Body size, skeletal biomechanics and habitual behaviour: A bioarchaeological approach to social and economic change in the Neolithic and Copper Age central Mediterranean

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To Josephine and Harlow. Thank you for everything.

DECLARATION

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text (see Chapter Two). It has not been previously submitted, in part or whole, to any university of institution for any degree, diploma, or other qualification. In accordance with the Department of Archaeology guidelines, this thesis is does not exceed 80,000 words, and it contains less than 150 figures.

Signed:

Date: 20th January 2020

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Cambridge

BODY SIZE, SKELETAL BIOMECHANICS AND HABITUAL BEHAVIOUR: A BIOARCHAEOLOGICAL APPROACH TO SOCIAL AND ECONOMIC CHANGE IN THE NEOLITHIC AND COPPER AGE CENTRAL MEDITERRANEAN.

Eóin W. Parkinson

The central Mediterranean during the 4th-3rd millennia BC is traditionally considered a period of economic and social transformation between the Neolithic and Bronze Age, characterised by agricultural intensification, technological innovation, and the emergence of gendered society. This project directly investigates these social and economic processes through a bioarchaeological approach which investigates body size, as reflective of physiological and nutritional stress, and long bone skeletal biomechanics, as reflective of habitual behaviour. This research uses metric data derived from 3D models of humeri, femora and tibiae in 17 human skeletal assemblages from across the central Mediterranean and features comparative analysis with a large sample of individuals spanning the Upper Palaeolithic to Modern periods. The application of 3D scanning also enabled the use of novel methods in the analysis of fragmented skeletal remains. The analysis of body size documents a pronounced reduction in body mass and stature during the Neolithic, followed by a gradual recovery in the Copper and Bronze Ages. The results suggest that the transition to agriculture was initially challenging for early farming groups in the central Mediterranean, resulting in increased physiological and nutritional stress. The biomechanical analysis of the humerus found that the intensification of agriculture in the Copper Age was characterised by a wider range of manual behaviours, reflecting the introduction of diverse economic tasks and craft specialisation. The analysis of the humerus also found no evidence for sexual division of labour in the Copper Age, contrasting with the widely accepted models of social change that have been proposed for the period. The analysis of the lower limb observed a decline in robusticity following the Neolithic, indicating that Copper Age groups were less terrestrially mobile than Neolithic groups. The results of this thesis demonstrate the effectiveness of a bioarchaeological approach in exploring social and economic change in prehistory and provide a framework for future research on the Copper Age of the central Mediterranean.

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1 INTRODUCTION

1.1 Introduction

At 3200 cal. BC[1], the Iceman walked the Alps with his copper axe, as distinctive archaeological cultures developed and flourished throughout the Italian peninsula, Sicily and Sardinia, and Malta's already well-established megalithic tradition was ascending to its apex. The central Mediterranean during 4th and 3rd millennia BC was a mosaic of varied cultural traditions that were set over an extremely diverse physical landscape. Broadly ascribed to the Copper Age (3600-2200 cal. BC), the 4th-3rd millennia BC is also considered a period of gradual economic and social transformation between the Neolithic and Bronze Age that saw the intensification and diversification of agriculture, exploitation of new landscapes, technological innovations, and important social change.

This PhD project explores these social and economic processes from a bioarchaeological perspective that investigates spatial and temporal trends in body size and long bone morphology during the Neolithic and Copper Age. This research uses metric data from the humerus, femur and tibia derived from 3D laser scans to examine body size and morphological variation related to habitual behaviour in 17 Neolithic and Copper Age human skeletal assemblages from across the Italian peninsula, Sardinia and Maltese Islands. Many of these assemblages represent communal burials, consisting of disarticulated and fragmentary human remains, and therefore an important component of this project addresses the methodological challenges of working with such challenging material. Although the focus of this thesis is the Neolithic and Copper Age, this study also features a comparative analysis of 224 individuals from the Upper Palaeolithic, Mesolithic, Bronze Age, Roman, Medieval and Modern periods derived from published literature (Ruff, 2018c). This long-term perspective enables the Neolithic and Copper Age to be placed within their broader temporal context of largescale trends across the *longue durée* of the Late Pleistocene and Holocene.

This chapter introduces the methodological framework of the research and the core social and economic themes that will be discussed and explored throughout the thesis. An overview of the methodologies is provided, followed by an introduction to the archaeological context of the central Mediterranean, before the individual research questions are introduced and discussed. The chapter ends with a summary of the thesis structure.

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[1] See Table 3.2 (Chapter Three) for details about the treatment of radiocarbon dates and calibration.

1.2 The social and economic context

The central Mediterranean Copper Age is traditionally considered a period of social change, settlement expansion, technological innovation, and economic intensification and diversification (Cazzella and Guidi, 2011). Previous scholars have discussed, theorised and debated these economic (Barker, 1981, 1999, 2005; Robb, 2007) and social (Cardarelli, 2015; Cocchi Genick, 2004; Robb, 1994b; Whitehouse, 1992, 2001) themes at length, arguing towards the emergence of gendered societies, intensification of agriculture and a growing reliance on pastoralism, with these processes becoming fully developed in the Bronze Age and Iron Age. However, the transitional qualities of the Copper Age are such that the period has been almost exclusively studied as a footnote to larger developments in the Neolithic and Bronze age. As a result, the central Mediterranean Copper Age in itself remains a neglected period of study and these processes have yet to be explored using a bioarchaeological approach. Table 1.1 provides a summary of the economic and social changes that are associated with the central Mediterranean Copper Age that are discussed in full in Chapter Two.

Table 1.1: General models of social and economic change for the Neolithic and Copper Age in the central Mediterranean.

	Neolithic	Copper Age	References
Economy	- Introduction of agriculture - Traditional 'Neolithic package' crops and domesticated animals	- Agricultural intensification and diversification, mixed agriculture - Increasing reliance on pastoralism? - Emergence of craft specialisation	Barker (1999; 2005), Cazzella and Guidi (2011), Malone (2003), Pessina and Tiné (2018), Robb (2007)
Burial	- No clear social distinction	- Gendered material culture in burials *i.e. Male =daggers, Female = body adornment* - Social differentiation in funerary treatment (?)	Barfield (1986), Whitehouse (2001), Dolfini (2006; 2015), Robb (2007)
Iconography	- Varied expression of body imagery, *i.e. Figurative art depicting female or ambiguous gender*	- Gendered symbolism *i.e. Males = Weapons, hunting, Female = body adornment, biological features*	Whitehouse (1992; 2001), Robb (1994, 2007), Holmes & Whitehouse (1998), Cocchi Genick (2004)
Physical activity	- No clear sex/gender based division of labour - Decreased mobility associated with sedentism	- Evidence for gender/sex based division of labour - Increased signs of terrestrial mobility with pastoralism	Robb (1994c)

In his critical review of central Italian prehistory, Barker (1981) challenged the traditional views of Copper Age economy and society that characterised the period as a brief horizon of nomadic warrior pastoralists (Puglisi, 1959; Trump, 1966). There is some zooarchaeological and archaeological evidence to suggest that pastoralism played an increasingly important role over the duration of the Copper Age (Barker, 1999; Robb, 2007), although Italian scholars have begun to question whether this narrative has been overemphasised (Cardarelli, 2015; Manfredini, 2014) and the period is more so characterised by mixed agriculture (Barker 1981; 1999). Discoveries of large settlement sites throughout the central Mediterranean suggest that Copper Age communities were more stable than previously thought (Anzidei *et al*., 2007, 2012; Bernabò Brea *et al*., 2011; Cazzella and Moscoloni, 1999; Fugazzola Delpino *et al*., 2003; Manfredini, 2014; Manunza et al., 2014; Webster and Webster, 2017), further calling into question the traditional themes of nomadism and population mobility. Robb (1994c) hypothesised that Copper and Bronze Age groups would display skeletal evidence for overall good nutritional status, likely related to the increased consumption of dairy products and animal protein associated with pastoralism. Palaeodietary studies on Copper Age groups from across the central Mediterranean have begun to explore subsistence change during the 4th and 3rd millennia BC (Cianfanelli *et al*., 2015; De Angelis *et al*., 2019; Lai, 2008, 2015; Martinez-Labarga *et al*., 2016), but have shown some regional variation in dietary habits.

As summarised in Table 1.1, social change in central Mediterranean prehistory has more often been explored through indirect artefactual and archaeological evidence. In particular, Copper Age gender ideology has been primarily theorised using indirect iconographic (statue stelae, figurines and rock art) and funerary evidence, generating hypotheses that have yet to be explored with bioarchaeological data. Whilst bioarchaeological studies exploring social change and gender ideology have been undertaken for the Neolithic (Robb, 1994a, 1997) and Iron Age (Sparacello *et al.*, 2011; Sparacello *et al*., 2015), no study of the Copper Age has been undertaken, despite evidence for important changes at this time. In a review of the current state of gender archaeology in Europe, Robb and Harris (2018) emphasised the need to incorporate bioarchaeological data related to everyday life (diet, mobility and physical activity) into future research programmes, and place less weight on burial evidence and art.

In an early attempt at this approach, Robb (1994c) proposed a model for skeletal change in the Italian Metal Ages that falls in line with the economic and social processes that are traditionally associated with the Copper Age (Table 1.1). Robb's (1994c) model hypothesised that Neolithic individuals would exhibit skeletal evidence for lower levels of mobility, in contrast to Copper Age and Bronze Age groups who would be expected to display skeletal evidence for increased mobility comparable to pre-agricultural groups due to increased reliance on transhumant pastoral agriculture. Alongside evidence for increased mobility, Robb predicted that Copper Age, Bronze Age and Iron Age groups would exhibit greater sexual dimorphism, reflecting the emergence of gendered society and specialised gender roles.

This model has since been partly evaluated in a series of studies examining long bone cross-sectional geometry in Italian prehistoric populations (Marchi *et al*., 2011; Sparacello and Marchi, 2008; Sparacello, 2013; Sparacello *et al*., 2011; see Section 1.3). Sparacello *et al.*'s (2011) study showed that Italian Iron Age groups exhibited greater sexual dimorphism and evidence for sexual division of labour than Neolithic groups, thus supporting Robb's model, but no study of earlier Copper Age or Bronze Age groups has been undertaken to establish when this marked sexual division of labour first emerged. Marchi *et al*. (2011) tested Robb's (1994c) hypothesis on Copper Age mobility by investigating diachronic trends in lower limb robusticity and reported a decline in mobility following the Neolithic. However, their study largely relied on available Copper Age comparative material from central Europe. As a result, Marchi *et al.*'s (2011) study might not be reflective of the region-specific trends that were proposed by Robb (1994c) and there is a need to re-evaluate the model using Copper Age data from the central Mediterranean region.

1.3 Methodological context

1.3.1 Long bone cross-sectional geometry

Analysis of long bone cross-sectional geometry is a well-established method of reconstructing habitual behaviour from the human skeleton (Ruff and Larsen, 2014; Ruff, 2018a). This approach relies on functional adaptation of bone tissue and the ability of long bones to respond to mechanical stimuli associated with habitual behaviour (Lanyon *et al.*, 1982; Ruff *et al*., 2006b; Hart *et al.*, 2017). Estimates of the intensity and direction of *in vivo* mechanical loading can be made by way of a biomechanical approach that models the long bones as structural beams and quantifies their cross-sectional properties related to strength and shape (Huiskes, 1982; Ruff, 2019). This enables biological anthropologists to infer patterns of manual activity from the upper limb and mobility behaviour from the lower limb (Shaw and Stock, 2009a. 2009b)[2].

The long bone cross-sectional geometry approach has been used to explore skeletal adaptations to subsistence change (Bridges, 1989; Cameron and Pfeiffer, 2014; Sládek *et al*., 2016; Sparacello and Marchi, 2008; Stock and Pfeiffer, 2004; Ruff *et al*., 2015), terrestrial

[2] A full discussion on the methodology and application of long bone cross-sectional geometry is provided in Chapter Six (upper limb) and Chapter Seven (lower limb).

mobility (Holt, 2003; Macintosh *et al.*, 2014; Sládek *et al.*, 2006a, 2006b), adaptations to terrain (Lambert *et al.*, 2013; Marchi *et al.*, 2006; Ruff, 1999; Ruff *et al.*, 2006a) and social change (Sparacello *et al.*, 2011, 2015) in past populations. Recently, long bone cross-sectional geometry has been used to investigate bone atrophy related to chronic disease in archaeological populations (Mansukoski and Sparacello, 2018; Sparacello *et al.*, 2016). Whilst a range of approaches have been developed to reconstruct activity from skeletal human remains (Jurmain *et al.*, 2012; Larsen, 2015), cross-sectional geometry offers an objective means of quantifying and exploring habitual behaviour in past populations that has benefits over other approaches that rely on activity-related pathology or analysis of muscle attachment sites (Waldron and Rogers, 1991; Wallace *et al.*, 2017; Wilczak *et al.*, 2017).

The application of long bone cross-sectional geometry to prehistoric European populations charts a decline in post-cranial robusticity throughout the Late Pleistocene and Holocene (Holt and Formicola, 2008; Holt *et al.*, 2018a), as part of a larger evolutionary trend (Shaw and Stock, 2013; Ruff *et al.*, 1993). In addition to a general reduction in robusticity, patterns of upper limb asymmetry changed throughout much of Europe with the adoption of food production tasks (Sládek *et al.*, 2016, 2018). In the lower limb, a decline in robusticity most prominently occurred following the transition to agriculture, associated with a reduction in terrestrial mobility with the shift to sedentism (Macintosh *et al*., 2014; Ruff *et al.*, 2015). Research has shown, however, that early agricultural groups in the central Mediterranean do not show the reduction in lower limb robusticity that is characteristic of wider Europe following the adoption of agriculture (Lambert *et al.*, 2013; Marchi, 2008; Marchi *et al.*, 2006, 2011; Ruff *et al.*, 2006a). These studies highlight the potential of the central Mediterranean to reveal unique regional trends in post-cranial robustly and patterns of habitual behaviour, but also stress the importance of undertaking focused regional studies. Whilst the impact of the initial transition to agriculture on post-cranial robusticity has been extensively investigated, there are few comprehensive studies focused on established agricultural societies. Within the central Mediterranean, no studies have been undertaken on human remains from the Copper Age or central Mediterranean islands, despite the interesting social, economic and environmental factors that are unique to these two contexts.

1.3.2 Body size: stature and body mass

Estimates of stature and body mass are important elements of osteological research and the relationship between body size, physiological stress and nutritional status has long been used by bioarchaeologists and economic historians to understand social and economic circumstances in the past[3]. Stature is commonly argued to be under stronger genetic control (Martiniano *et al.*, 2017; Silventoinen *et al.*, 2003), but the heritability of height has likely been overemphasised (Wells and Stock, 2011) and final adult stature has been shown to be affected by life history factors such as growth impairment and childhood malnutrition (Jee *et al.*, 2014; de Onis and Branca, 2016; Victora *et al.*, 2008). The application of regression formulae to long bone lengths is the most common approach to estimating stature from skeletal remains (Ruff *et al.*, 2012a; Trotter, 1970), but other approaches rely on partial reconstruction of the human skeleton (Raxter *et al.*, 2006). Body mass can be estimated using articular dimensions, and is more susceptible to variation throughout life than stature, although current methods for estimating body mass from skeletal remains do not fully account for the extremes of emaciation and obesity (Young *et al.*, 2018). With the relationship between life history and body size, analysis of stature and body mass provides important insights into physiological stress and changes in nutritional status in response to economic and social change.

Body size has been widely used to explore nutritional status in prehistoric groups from Europe (Ehler and Vančata, 2009; Formicola and Holt, 2007; Macintosh et al., 2016; Niskanen *et al.*, 2018; Piontek and Vancata, 2012), North Africa (Stock *et al.*, 2011) and North America (Mummert *et al.*, 2011). A particular emphasis has also been placed on the transition to agriculture, where a decrease in body size coincides with an increase in skeletal stress markers among early agriculturalists (Cohen and Armelagos, 1984; for review see Stock and Pinhasi, 2011). This universal trend is interpreted as reflecting an overall deterioration in health as human groups became sedentary and aggregated into larger settlements with poorer sanitation and came into contact with zoonotic diseases. It has also been argued that the shift from a highly diverse hunter-gather diet to dependence on a limited range of domesticated plants and animals resulted in heightened nutritional stress among early agriculturalists. A reduction in body size following the transition to agriculture has been previously observed in the central Mediterranean (Barbieri *et al.*, 2017; Danubio *et al.*, 2017; Floris *et al.*, 2012; Holt *et al.*, 2018b; Martella *et al.*, 2016), but also during the Roman period (Floris *et al.*, 2012; Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016). The majority of these studies have interpreted trends in body size within an exclusively economic framework and body size in established agricultural societies during the Copper Age and Bronze Age have not been fully investigated. In a study on central-southern Europe, the reduction in body size associated with the Neolithic also was accompanied by greater sexual dimorphism in body size, which was argued as evidence for the emergence of social inequality that negatively impacted on women (Macintosh

[3] A detailed discussion on body size estimation methods and their application is provided in Chapter Five.

et al., 2016). Macintosh *et al.* (2016) also showed that sexual dimorphism in body size decreased after the Neolithic during the Bronze and Iron Ages, and highlighted the importance of also interpreting body size data within a social framework and providing long-term temporal context.

1.4 Research questions

To explore the social and economic processes that are associated with the 4th-3rd millennia BC in central Mediterranean (Table 1.1), this thesis sets out to answer three questions relating to the social and economic context of spatial and temporal trends in body size, upper limb biomechanics and lower limb biomechanics. Each research question is introduced below, together with a short discussion on the expected outcomes of the analysis. Each question and the expected outcomes are returned to again in the relevant results chapter later in the thesis.

1.4.1 Research Question One

1) *Do body size and nutritional status change in response to economic and social change during the 4th-3rd millennia BC?*

The first research question investigates what impact the social and economic changes during the Neolithic and Copper Age had on body size and nutritional status. In line with broader Europe, it is expected that there was a decrease in body size with the onset of agriculture, followed by a recovery in body size during the Metal Ages. It is also expected that body size remained stable throughout the remainder of the Holocene, although fluctuations might have occurred in Roman and post-industrial populations. Following the widely accepted social models that have been proposed for central Mediterranean prehistory (Robb, 1994b; Whitehouse, 2001), the development of binary gender identities closely aligned to biological sex in the Metal Ages might be expected to manifest in increased sexual dimorphism in body size.

1.4.2 Research Question Two

2) *Do patterns of mechanical loading in the upper limb reflect the intensification and diversification of agriculture during the Copper Age? Is there evidence for greater sexual division of labour among Copper Age groups?*

Upper limb biomechanics provide insights into patterns of manual physical behaviour in past populations. The analysis of long-term trends in upper limb cross-sectional geometry from the

Mesolithic to Modern periods is expected to reflect the overall reduction in post-cranial robusticity that is characteristic of wider Europe during the Holocene. However, increased upper limb robusticity might be observed in agricultural societies, reflecting the introduction of labour-intensive food processing tasks. Furthermore, with the suggestion that agriculture intensified after the Neolithic, upper limb robusticity is expected to have increased during the Copper Age. Following the emergence of craft specialisation and economic diversification in the Metal Ages, the analysis of upper limb biomechanics might also be expected to show evidence for a wider range of manual activities being undertaken from the Copper Age onwards. Finally, increased sexual dimorphism in upper limb cross-sectional geometry might be expected from the Copper Age onwards with the emergence of gendered society and specialised gendered tasks.

1.4.3 Research Question Three

3) *Is there evidence for high levels of terrestrial mobility in the Copper Age? Do Neolithic and Copper Age groups exhibit spatial variation in lower limb robusticity?*

Lower limb biomechanics can provide insights into mobility behaviours and levels of terrestrial mobility. Analysis of lower limb biomechanics is undertaken here in order to establish if mobility behaviours changed between the Neolithic and Copper Age. On a broader level, it is expected that the analysis of long-term trends in lower limb biomechanics will document a gradual decline in lower limb robusticity from the Upper Palaeolithic to the Modern period, but that there will be considerable spatial variation within the Neolithic and Copper Age time periods. Within the Neolithic, southern Italian groups might be expected to exhibit decreased lower limb robusticity relative to northern Italian groups, who have previously been documented as having robust lower limbs (Marchi *et al.*, 2006; Sparacello and Marchi, 2008). Within the Copper Age, considerable spatial variation in lower limb cross-sectional geometry is expected given the obvious differences in landscape settings between samples (i.e. mountainous areas vs. small islands). Lastly, this question will test Robb's (1994c) hypothesis that Copper Age groups were more terrestrially mobile due to an intensification of pastoralism, reassessing the results of Marchi *et al.*'s (2011) study.

1.5 Thesis structure

The thesis is centred around three chapters that examine the questions posed above through analysis of: 1) body size, physiological stress and nutritional status, 2) upper limb morphology and manual physical activity, and 3) lower limb morphology and mobility behaviour. The overall structure of the thesis is described below.

1.5.1 Background, materials and methods

Chapter Two provides an overview of the archaeological record for the central Mediterranean Neolithic and Copper Age. Key themes relating to chronology, subsistence, settlement and material culture are addressed for each sub-region in order to frame the bioarchaeological approach of the succeeding results chapters. Chapter Two is also bookended by short overviews of the preceding Mesolithic and succeeding Bronze Age which provide additional contextualisation for the Neolithic and Copper Age, as well as providing a backdrop to the analysis of long-term trends presented in Chapters Five-Seven. Chapter Three provides the full contextual and chronological details for all the skeletal collections analysed in this study. Each site is presented by sub-region (i.e. North Italy, Central Italy), and a brief summary of each site's discovery, excavation, archaeological context and chronology is provided, alongside overviews of any previous bioarchaeological research. Chapter Three also introduces the published comparative data for body size and long bone cross-sectional properties from the Ruff (2018c) European dataset that spans the Upper Palaeolithic to the Modern periods. Chapter Four discusses the methodological challenges and practical considerations of working with fragmented and disarticulated human remains. In particular, the technical approaches relating to bone length estimation (3D digital reconstruction, 3D digital superimposition) and body mass estimation (3D shape fitting) are introduced and explained.

1.5.2 Results and conclusions

Approaching each main research question in turn, Chapters Five, Six and Seven each consist of an Introduction, Materials & Methods, Results, Discussion and Conclusion, and are structured so as to function as standalone research papers. The findings are then drawn together in the concluding Chapter Eight.

Chapter Five presents the combined analysis of stature and body mass among prehistoric groups from the Maltese Islands, Sardinia and the Italian peninsula. Further comparative analysis using the Ruff (2018c) database enables a study of body size trends over ca. 24,000 years of central Mediterranean prehistory. Chapter Six analyses cross-sectional geometric properties of the humerus in order to investigate patterns of manual activity and socio-economic change in the Neolithic and Copper Age. Synchronic and diachronic comparisons of solid cross-sectional geometric properties between the Neolithic and Copper Age samples are made. Comparison with Mesolithic, Bronze Age, Roman, Medieval and

Modern samples (Ruff, 2018c) and analysis of asymmetry in the humerus in a sub-set of articulated individuals are also examined. Chapter Seven analyses the cross-sectional geometry of the femur and tibia in order to investigate changing levels of mobility, subsistence economy and human-landscape interaction. The concluding chapter (Chapter Eight) summarises the results of the thesis and brings together the findings of each results chapter in order to offer new directions for the study of economic and social change in the later prehistory of the central Mediterranean.

1.5.3 Supplementary material

Supplementary materials that are referenced throughout the text are included in four Appendices (A-D). Appendix A provides additional contextual details on the study materials introduced in Chapter Three. Appendix B provides supplementary data related to the analysis of body size in Chapter Five, whilst Appendix C and D provide supplementary data on the analysis of upper and lower limbs presented in Chapters Six and Seven.

2 The archaeological context of the Neolithic and Copper Age in the central Mediterranean

2.1 Introduction

The prehistoric central Mediterranean comprises a rich and varied archaeological record of pronounced cultural developments that were set over an extremely diverse physical landscape (Figure 2.1). The study of prehistory in the central Mediterranean has stood somewhat separate from wider continental traditions, with the region itself divided into distinctive sub-regional academic traditions (Guidi, 2010). As a consequence of these localized research traditions, the application of archaeological science has been far more widespread in the central-northern Italian peninsula than in southern Italy and the surrounding islands. A long tradition of physical anthropology that is firmly rooted in the natural sciences has also enabled consistent and dedicated study of past human populations in the central Mediterranean since the 19th century (Piombino-Mascali and Zink, 2011).

The following chapter provides the archaeological background to the research presented in this thesis (6000-2300 cal. BC)[4]. The chapter is divided into two separate Neolithic and Copper Age sections, which contain an initial overview of the dominant themes associated with each period. This is followed by a summary of each geographic sub-region (Figure 2.2) with regard to chronology, economy, and the settlement and funerary records. In addition to this, a short discussion on the preceding Mesolithic and succeeding Bronze Age is also provided so as to adequately frame the economic and social changes that occurred during the 4th and 3rd millennia BC, and in order to provide additional context for the long-term trends discussed in Chapters Five, Six and Seven. Not all of the sub-regions discussed below are represented in the bioarchaeological analysis presented in this thesis (i.e. Sicily, Neolithic central Italy) although a full discussion on all sub-regions is offered here for the purpose of providing adequate and coherent context.

[4]**Declaration**: The contents of this chapter have been submitted to the *Journal of World Prehistory* as part of a collaborative original research paper provisionally entitled 'Radiocarbon dated trends in the prehistory of the central Mediterranean' which synthesises the radiocarbon record for central Mediterranean prehistory. I am the lead author (co-authors in order are T. Rowan McLaughlin, Carmen Esposito, Simon Stoddart and Caroline Malone) and I confirm that the following text, figures and tables are my own work.

Figure 2.1 – Terrain map of the central Mediterranean displaying location of sites mentioned in the text. 1) 'Ötzi' the Tyrolean Iceman, 2) Latsch-Vinschgau, 3) Lovere-Colle del Lazzaretto, 4) Vollien, 5) Saint-Martin-de-Corléans, 6) Villeneuve, 7) Monte Covolo, 8) Civate Group, 9) Remedello, 10) Sammardenchia, 11) Arene Candide, 12) Spilamberto, 13) Lugo di Romagna, 14) Forlì-Celletta, 15) Conelle di Arcevia, 16) Camerano-Fontenoce Group, 17) Ripoli, 18) Strette, 19) Ponte San Pietro Group, 20) La Marmotta, 21) Ortucchio, 22) Colli Albani Group, 23) Passo di Corvo, 24) Coppa Nevigata, 25) Masseria Pozzelle, 26) Tegole, 27) La Starza di Ariano Irpino, 28) Caivano, 29) Pontecagnano, 30) Toppo Daguzzo, 31) Eboli, 32) Paestum-Gaudo, 33) Buccino, 34) Trasano, 35) Laterza, 36) Roca Vecchia, 37) Capo Alfiere, 38) Li Muri, 39) Porto Leccio, 40) Su Coluru, 41) Monte d'Accoddi, 42) Corbeddu, 43) Cuccuru S'Arriu, 44) Scab'e Arriu, 45) San Benedetto-Iglesias, 46) Monte Pranu, 47) Grotta Oriente, 48) Gruppo dell'Isolidda, 49) Grotta dell'Uzzo, 50) Troina, 51) Case Bastione, 52) Scintilia, 53) Piano Vento, 54) Santa Verna, 55) Skorba, 56) Għar Dalam. Map produced in QGIS3; Base map: www.naturalearthdata.com/downloads/10m-physical-vectors, 1:10m Physical Vectors; DEM: www.viewfinderpanoramas.org/dem3.

Figure 2.2 – Map of the central Mediterranean displaying geographical sub-regions discussed in this chapter and throughout the thesis. Sub-regions correspond to modern administrative regions and political borders. Map produced in QGIS3; base map: www.naturalearthdata.com 1:10m Physical Vectors; Italian administrative borders: ISTAT: Istituto Nazionale di Statistica Census Database, www.istat.it/it/archivio/222527.

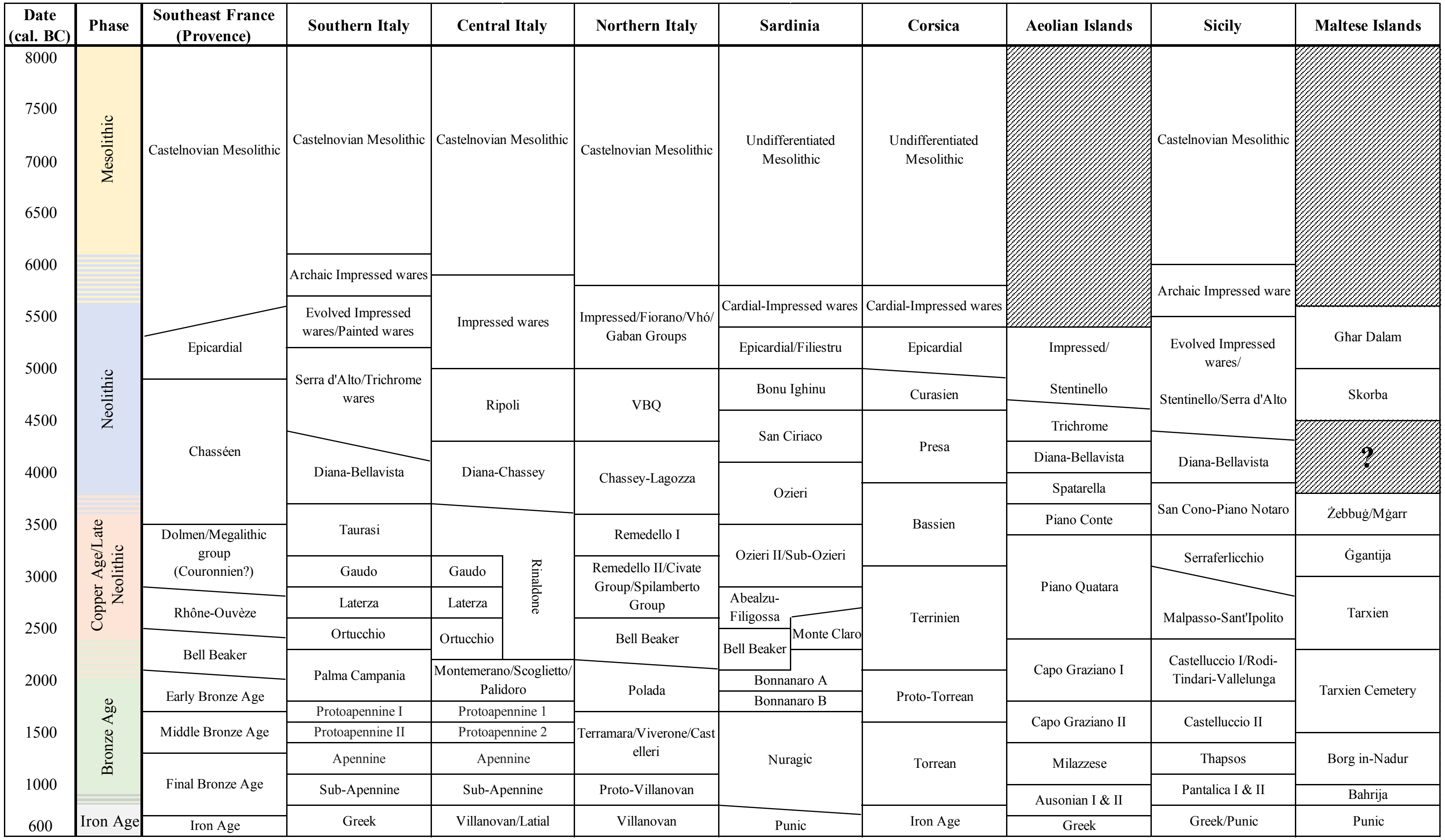


Figure 2.3 – Simplified relative chronology for central Mediterranean later prehistory (8000-600 cal. BC) (Alberti, 2013b; Albore Livadie et al., 2019; Aurino, 2013; Carboni and Anzidei, 2013; Cocchi Gennick , 2013; De Marinis, 1997, 1999; Depalmas, 2009; Desideri et al., 2012; Dolfini, 2010; Fanti et al., 2018; Leighton, 1999, 2005; Malone, 2003; Malone et al., 2009c; 2019a; Melis, 2013; Mottes et al., 2009; Negroni Catacchio et al., 2016; Pearce, 2013; Pessina and Tiné, 2018; Tramoni and D'Anna, 2016; Trump, 2002; Lo Vetro and Martini, 2016; Visentini, 2006; Zoppi et al., 2001).

2.2 Prelude: the Mesolithic

2.2.1 Mesolithic of the Italian peninsula

The Mesolithic period in the central Mediterranean (ca. 9700 to 6000 cal. BC) is broadly characterised by the earlier ‘Sauvetterrian’ and later ‘Castelnovian’ lithic industries, whilst the surrounding islands are associated with undifferentiated lithic traditions (Pluciennik, 2008; for detailed overview see Lo Vetro and Martini, 2016). The settlement record for the central Mediterranean Mesolithic mostly consists of caves and rock-shelters. Northern Italy has a particularly well documented Mesolithic, with sites known in the Trieste Karst, Adige Valley, Liguria and Tuscan-Emilian Apennines (Biagi *et al.*, 1988; Kompatscher *et al.*, 2016; Scoz *et al.*, 2015; Visentin and Carrer, 2017), and more recently open-air sites along the southern Po Plain (Visentin *et al.*, 2014, 2016), demonstrating use of both lowland and upland territories (Fontana and Visentin, 2016). In central and southern Italy, local wild terrestrial and marine resources were exploited in a pattern consistent with the seasonal utilisation of coastal caves and rock-shelters (Pluciennik, 2008; Lo Vetro and Martini, 2016). In general, particular emphasis for coastal sites appears to be a southern phenomenon, as on the Salento peninsula in Puglia, in contrast to greater exploitation of inland areas in central Italy (Pluciennik, 1994).

2.2.2 Mesolithic of the central Mediterranean islands

In the island contexts of the central Mediterranean, Sicily has remained at the centre of discussions pertaining to the Mesolithic. A cluster of cave sites with Mesolithic occupation and burial are known in north-west Sicily, the classic site being Grotta dell’Uzzo (Leighton, 1999; Tagliacozzo, 1994) and more recent research has expanded to the Gruppo dell'Isolidda and Grotta Oriente situated on islands north-west of Sicily (D’Amore *et al.*, 2010b; Lo Vetro and Martini, 2016; Lo Vetro *et al.*, 2016). A dearth of Mesolithic activity in southern Sicily (Leighton, 1999; Lo Vetro and Martini, 2016) resembles the situation in the Maltese Islands, which have no evidence for Mesolithic occupation (Bonanno, 2000), in line with many smaller Mediterranean islands (Cherry and Leppard, 2018). In Sardinia and Corsica, the Mesolithic period is largely similar to that of peninsular Italy although some differences stemming from the natural isolation of the two islands are reflected in the archaeological record. Mesolithic settlement of the Tyrrhenian islands is defined by short term and discontinuous occupation of small coastal rock-shelters, such as Strette on Corsica (Costa *et al.*, 2003) and Porto Leccio on Sardinia (Dini and Tozzi, 2012), but Mesolithic presence in larger caves is documented in Sardinia at Su Coloru and Corbeddu (Lugliè, 2012, 2018). The Mesolithic economy of Sardinia and Corsica largely reflects exploitation of local wild terrestrial and marine resources. A significant reliance on the endemic small mammal *Prolagus sardus* (Vigne, 1998), and local raw materials (Costa *et al.*, 2003), suggests Mesolithic occupation of the Tyrrhenian islands was limited to seasonal visits by small seafaring groups from the Italian mainland.

2.3 The Neolithic of the central Mediterranean

The beginning of the Neolithic in the central Mediterranean has received much enthusiastic study, with general overviews having been provided by Italian and Anglo-American scholars (Malone, 2003; Pessina and Tiné, 2018; Robb, 2007). Most recently, a dedicated special issue of *Quaternary International* entitled 'The Neolithic expansion in the western Mediterranean: understanding a global phenomenon from regional perspectives' (Gibaja *et al.*, 2018) provides updated accounts of the beginning of the Neolithic in southern Italy and Sicily (Natali and Forgia, 2018), central Italy (Radi and Petrinelli Pannocchia, 2018), Sardinia and Corsica (Lugliè, 2018) and the Po Valley (Starnini *et al.*, 2018), alongside a series of broader central-western Mediterranean perspectives (Guilaine, 2018; Mazzucco *et al.*, 2018). The transition to agriculture in the central Mediterranean in the run-up to the 6th millennium BC brought with it technological innovations, domesticated animals and traditional 'Neolithic package' crops (Barker, 1999; Malone, 2003; Pessina and Tiné, 2018), alongside rapid population growth and settlement density. The spread of the Neolithic to northern Italy can be viewed as a rapid series of parallel maritime expansions along Adriatic and Tyrrhenian coastlines, including Sardinia and Corsica (Pearce, 2013), the speed of which is documented by the early Neolithic presence in Liguria ca. 5800 cal. BC (Binder *et al.*, 2017). At the same time, a terrestrial diffusion ran across the northern Mediterranean zone (Mazzucco *et al.*, 2017).

The Early Neolithic economy of the central Mediterranean was based around cereal and some legume cultivation, along with some exploitation of wild plants and fruits, enabled through a new lithic repertoire (Mazzucco *et al.*, 2017, 2018; Ucchesu *et al.*, 2017; Table 2.1). For the Italian peninsula, animal husbandry was based on cattle, pig and ovicaprines, with exploitation of locally available wild animals playing a marginal role (Tagliacozzo, 2005; Vander Linden and Silva, 2018). In Sardinia, extensive exploitation of endemic wild lagomorphs continued in the earliest Neolithic contexts followed by increasing reliance on domesticated animals (Malone, 2003). The reliance on terrestrial resources evidenced in the archaeological record is further supported by palaeodietary studies, even among groups living on the coastal plains of southern Italy (Craig *et al.*, 2006) and maritime Alps in northern Italy (Le Bras-Goude *et al.*, 2006), and follows a Europe wide trend for the Neolithic (Schulting, 2011). There is some regional variation in Neolithic agricultural practices, especially in the north of Italian peninsula (Pessina and Tiné, 2018). In a recent study, Vander Linden and Silva (2018) demonstrated how faunal assemblages for the Early Neolithic in the Adriatic area display latitudinal variation, with southern Italian and Dalmatian assemblages containing more ovicaprines than northern Adriatic assemblages, which are dominated by more water-dependent herds of pig and cattle, reflecting wetter climate in the north. A similar situation is seen on the Maltese Islands, where faunal studies indicate that the semi-arid conditions of the small archipelago necessitated a system of animal husbandry that was focused towards on ovicaprines, over pigs and cattle (Malone *et al.*, 2019b).

Villages appear to have been central to Early Neolithic life, especially in southern Italy, with burial also occurring within domestic contexts (Conati Barbaro, 2008; Table 2.1), although by the Middle-Final Neolithic formalised and demarcated burial areas began to emerge, often overlying earlier settlements (Pessina and Tiné, 2018; Quarta *et al.*, 2005; Robb, 1994a, 2007). The Final Neolithic is associated with the intensification of mixed agriculture and small scale pastoral systems along with more dispersed settlement (Barker, 1999; Malone, 2003), as part of an overall Mediterranean wide trend (Barker, 2005; Sollars, 2005) and progressive development towards the Copper Age. Where areas of previous intense human occupation in southern Italy and Sicily declined, namely the Tavoliere and Catania planes (Fiorentino *et al.*, 2013; Leighton, 1999; Skeates, 2015; Tusa, 1992;Whitehouse, 2013), there was expansion into a variety of upland areas (Foxhall *et al.*, 2007; Giannitrapani *et al.*, 2014; Leighton, 2005; Putzer *et al.*, 2016), but also small islands such as Malta (Trump, 1966b). In central and northern Italy, Later and Final Neolithic settlement is focused on wetland areas (Malone, 2003; Skeates, 2013), alongside expansion into upland Alpine and Apennine areas (Mottes *et al.*, 2009), and continued use of sub-coastal cave sites in Liguria (Pessina and Tiné, 2018).

2.3.1 Neolithic southern Italy and Sicily

The earliest Neolithic settlements in Italy are located on the lowland coastal areas in the south-east, along the Apulian Tavoliere and Salento peninsula (Brown and Alexander, 2013; Natali and Forgia, 2018; Whitehouse, 2013) where the large ditch-enclosed settlements, or *villaggi trincerati,* then developed. With some 766 such sites of varying size documented on the Tavoliere and surrounding areas in high densities – up to one site per 3km^2 (Whitehouse, 2013) – the Neolithic of southern Italy marks a point of major population increase. The majority of villages consisted of small groups of farmsteads set within larger perimeter ditches spanning areas of 4-7 hectares, such as Masseria Pozzelle (Jones, 1987), although mega-sites, such as Passo di Corvo, were as large as 40 hectares (Tiné, 1983). Whilst the ditched villages where clearly not occupied all at once, the Apulian Tavoliere represents the densest area of settlement anywhere in Neolithic Europe (Brown, 2003) that peaked in the mid-6th millennium BC (Fiorentino *et al.*, 2013; Whitehouse, 2013), representing a major demographic event in a geographical area with a limited preceding Mesolithic presence. The precise function of the ditches has been debated, with various practical interpretations such as defence, water storage or herd corralling having been proposed (for overview see Skeates, 2000), although they likely held an important social and symbolic role alongside any practical use (Robb, 2007; Skeates, 2000, 2015). Early Neolithic funerary practices were intertwined with the domestic sphere, with burial often in settlement ditches, although other funerary practices are documented, such as curation of skeletal elements (Dolfini, 2015; Robb, 2007).

From south-east Italy, the Neolithic rapidly spread westward into Calabria (Morter, 2010) and Sicily (Leighton, 1999; Natali and Forgia, 2018; Tusa, 1992). In Sicily, Early Neolithic settlement was contained in ditched and walled village sites along eastern coastal planes (Malone, 2003; Pessina and Tiné, 2018) and in both caves, such as Grotta dell'Uzzo, and open-air along sites, such as Piano Vento, along the northern and southern coasts (Castellana, 1995; Leighton, 1999). By the Late and Final Neolithic, the Tavoliere was largely abandoned, likely due to a combination of environmental factors (Fiorentino *et al.*, 2013; Malone, 2003) and the ditched villages were frequently reused as places of burial (Manfredini and Muntoni, 2005; Robb, 1994a). During the Final Neolithic *Diana-Bellavista* phase, settlement shifted to upland and coastal areas (Ammerman, 1985; Morter, 2010; Pacciarelli and Talamo, 2011).

2.3.2 Early Neolithic of the Maltese Islands

The Maltese Islands were first settled towards the end of the 6th millennium BC, with occupation in caves, such as Għar Dalam (Despott, 1917), and open-air settlements at Skorba (Trump, 1966b, 2015) and Santa Verna (McLaughlin *et al.*, 2015). The Early Neolithic of the Maltese Islands falls within the southern Italian Middle to Final Neolithic cultural setting, with the Maltese *Għar Dalam* and *Skorba* phases representing southern variants of the Italian *Stentinello* and *Diana-Bellavista* phases respectively. The chronology of the Italian phases is not entirely contemporaneous with the Maltese sequence (pers. comm., McLaughlin, T.R. 2018; Figure 2.3), but this likely reflects the lack of radiocarbon dates for Sicilian and south Italian sequences. The economy for the earliest Neolithic in Malta parallels that of neighbouring areas, with reliance on traditional domesticated Neolithic crops and animals. At Skorba, the *Għar Dalam* phase settlement consisted of small oval huts enclosed within a stone boundary wall, reminiscent of the coeval sites in Sicily and southern Italy (Castellana, 1995; Guilaine and Cremonesi, 1987; Morter, 2010). *Skorba* phase settlement remains more elusive, with structures associated with the phase at Skorba interpreted as representing ‘shrines’, having produced numerous figurines, but no obvious occupation debris (Trump, 1966b, 2015).

2.3.3 Neolithic central Italy

Central Italy’s archaeological record is divided between the eastern Adriatic and western Tyrrhenian coasts, separated by the Apennine mountains. Whilst the Neolithic expansion along the Italian Adriatic coast occurred rapidly and in parallel to the Balkan Adriatic coast, the transition to the Neolithic on the western coast appears to have been more sporadic. The early presence of impressed pottery in Liguria, in north-west Italy, and on the islands of Sardinia and Corsica also suggests the spread of the Neolithic along Tyrrhenian Italy was rapid, and likely manifested as a maritime spread along the islands and coasts with minimal mainland interaction (Pearce, 2013; Radi and Petrinelli Pannocchia, 2018). Early Neolithic settlement in central Italy occurred on the lowlands and on terraces overlooking rivers and lakes (Malone, 2003; Malone and Stoddart, 1994; Radi and Petrinelli Pannocchia, 2018; Robb, 2007), as at the lake settlement of La Marmotta, Lazio, where extensive organic preservation has enabled detailed insights into Neolithic lifestyle (Bondioli *et al.*, 2000; Fugazzola Delpino and Mineo, 1995). Later Neolithic settlements such as Ripoli, Abruzzo, show the development of larger villages and the emergence of distinct burial areas (Radmilli, 1977).

2.3.4 Neolithic northern Italy

The north Italian Early Neolithic has been intensively studied and is characterised by a variety of regional ceramic traditions, consisting of the Ligurian impressed wares, along with the *Isolino*, *Fiorano*, *Vhò*, *Gaban* and *Fagnigola* groups in the Po valley and Alpine valleys (Bagolini, 1980; Pearce, 2013; Starnini *et al.*, 2018). The settlement record for the north Italian Early Neolithic is scant in contrast to the south, with much of the evidence stemming from the many so called *fondi di capanna*, large storage pits that were previously considered to be hut foundations (Robb, 2007; Starnini *et al.*, 2018). In general, however, the north Italian Early Neolithic settlement pattern is one of cave and rock-shelters in the west, as at Arene Candide in Liguria, and open-air villages in the east, such as at Lugo di Romagna (Emilia-Romagna) and Sammardenchia (Friuli-Venezia Giulia) (Pessina and Tiné, 2018). Middle and Later Neolithic burial in northern Italy is commonly defined by stone lined cist burials, which are seen in Liguria, Veneto and Trentino associated with the *Vasi a Bocca Quadrata* (VBQ) pottery style (Bernabò Brea *et al.*, 2010), and in the Alpine valleys, as at Villeneuve and Vollien in Aosta (Corrain, 1986; Mezzena, 1997). In contrast to central and southern Italy, palaeodietary and zooarchaeological evidence suggest that Neolithic groups in Liguria seem to have had greater reliance on pastoral agriculture and herding, which was more suited to the mountainous terrain of the region (Le Bras-Goude *et al.*, 2006; Pearce, 2013). Similar dietary trends are also seen further along the coast of the Ligurian sea in southern France (Le Bras-Goude *et al.*, 2010; Salazar-García *et al.*, 2018).

2.3.5 Neolithic Sardinia

In Sardinia, the arrival of the Neolithic signals complete discontinuity with the preceding Mesolithic, attested by stratigraphic information at Grotta Su Coloru (Luglié, 2009, 2018) and recent aDNA studies (Modi *et al.*, 2017), in contrast to southeast France (Perrin *et al.*, 2018). The Neolithic in Sardinia heralded a period of significant settlement expansion as indicated by the increased number of archaeological sites on the west coast especially (Luglié, 2009, 2018), in contrast to Corsica, where the Neolithic expansion was more muted. Middle Neolithic *San Ciriaco* and Late Neolithic *Ozieri I* sites are rarer in the mountainous east of Sardinia, and sites here tend to be caves (Webster and Webster, 2017). In spite of increasing dependence on sheep/goat through the Neolithic, marginal use of wild animals (Luglié, 2009; Malone, 2003) and wild fruits (Ucchesu *et al.*, 2017) appears to have continued in Middle and Late Neolithic contexts.

Caves appear to have been the focus of Early Neolithic burial in Sardinia (Skeates *et al.*, 2013; Melis, 2014). However, the emergence of small rock-cut *a forno* tombs during the Middle Neolithic in the mid-5th millennium BC, as at Su Cuccuru S'Arriu, Cabras, represents some of the earliest use of rock-cut tombs in the western Mediterranean (Santoni, 2000). Larger hypogea then developed during the late 5th millennium BC during the *San Ciriaco* phase (Melis, 2013; Salis *et al.*, 2015) and are well known for the Late Neolithic *Ozieri I* phase in the form of the *domus de janas*, which are found both in isolation and organised into large necropolises (Melis, 2014). The Late Neolithic in Sardinia also saw the introduction of monumental architecture in the north of the island, in the form of the unique step-pyramid at Monte d'Accoddi (Melis, 2011), but also to the very northeast in the form of megalithic tombs associated with the *facies Arzachena*, as at Li Muri (Lilliu, 1963).

2.4 The Italian Copper Age and Maltese 'Temple Period'

The 4th-3rd millennia BC in the central Mediterranean broadly correspond to the Copper Age, and are associated with marked economic, technological and social change. In particular, the period saw the proliferation of metallurgy and economic diversification (Barker, 1999; Cazzella and Guidi, 2011; Dolfini, 2014), and is associated with the emergence of a binary gender ideology closely aligned to biological sex (Cazzella and Guidi, 2011; Cocchi Genick, 2009;

Robb, 2007; Whitehouse, 1992, 2001). The Copper Age in the Italian peninsula has been historically divided into four main regional "cultures" with *Remedello* in the north, *Rinaldone* in the centre, *Guado* in the southwest and *Laterza* in the southeast (Barfield, 1971; Todaro and Girella, 2013; Trump, 1966a), whilst the islands accommodated distinctive insular cultural traditions (Figure 2.1). Until the 1990s the Italian Copper Age was considered a brief interlude between the Neolithic and Bronze Age that spanned the final centuries of the 3rd millennium BC (Whitehouse and Renfrew, 1974; see Barker, 1999). This chronological misunderstanding has unfortunately had a major impact on the study of social and economic change in the Copper Age, with the period all too often viewed as a prelude to the Bronze Age.

Barker (1981) challenged many of the traditional diffusionist interpretations of Italian Copper Age economy and society that emphasised themes of migration and nomadic pastoralism. Our understanding of the central Mediterranean Copper Age has continued to fundamentally change over the last two decades following the widespread application of radiocarbon dating, which has demonstrated that period spanned the majority of the 4th and 3rd millennia BC (ca. 3600-2200 cal. BC). Furthermore, the traditional Copper Age "cultures" of the central Mediterranean are now considered to represent regional burial traditions or metal artefact typologies (Dolfini, 2010, 2015), rather than representing any strict cultural group. Recent intensive excavation in the area south of Rome has particularly demonstrated the complex interplay between these "cultures", highlighting the chronological and geographical issues with these broad classifications (Anzidei *et al.*, 2007, 2016; Carboni and Anzidei, 2013). Despite recent developments, these broader cultural terminologies remain in use among Italian scholars and provide a useful framework for dividing up the study of the Copper Age in central Mediterranean (Cocchi Genick, 2011b; Dolfini, 2010). In the case of Malta, the Copper Age never came, and instead a sophisticated Late Neolithic megalithic tradition flourished on the islands from 3700-2300 cal. BC.

As with the Final Neolithic, a distinctive settlement record for the Italian Copper Age and Maltese Late Neolithic is scant, but in general the period saw a movement away from nucleated villages towards more dispersed settlement into a wider variety of landscape settings (Barker, 1999; Dolfini, 2015). Many Italian sites show continuity from the Late Neolithic to the Early Bronze Age (Baioni and Poggiani-Keller, 2013; Ingravallo, 1980; Silvestrini and Pignocchi, 1997; Talamo, 2006), and from the Early Neolithic to Late Neolithic in the case of Malta (McLaughlin *et al.*, 2015; Trump, 1966b), which suggests relative homogeneity in settlement patterns throughout the 4th and 3rd millennia BC. The settlement record for the Italian peninsula has, however, greatly improved in recent years as a result of developer-led archaeology

(Anzidei *et al.*, 2007; Baioni and Poggiani-Keller, 2013; Giola *et al.*, 2007; Manfredini, 2014; Tunzi *et al.*, 2013). Despite scarce settlement evidence in some regions, the large numbers of sizeable Copper Age cemetery sites in central Italy, Campania and Sardinia suggests considerable population increase during this period, which appears to be supported by palaeodemographic studies (Palmisano *et al.*, 2017; Stoddart *et al.*, 2019). This pattern is mirrored on the Maltese Islands, but instead a proliferation in megalithic ritual architecture stands in stark contrast to the scarce settlement evidence for the Late Neolithic.

The lack of open-air settlement evidence for Copper Age Italy was traditionally attributed to increased population mobility associated with the development of transhumant pastoralism (see Barker, 1981; Robb, 2007). Barker (1981) argued that the period was instead characterised by mixed agriculture and gradual development of agricultural intensification and specialisation leading to the Bronze Age. However, pervasive elements of the traditional 'nomadic pastoralist' narrative remain intact within mainstream scholarship. The mixture of upland and lowland activity in central Italy seems to corroborate the idea of a mixed agro-pastoralist economy (Manfredini *et al.*, 2009; Skeates, 1997), and the recent discoveries of substantial Copper Age settlements across the Italian peninsula have been put forth as evidence for greater stability among Copper Age groups and a historical overemphasis on the transhumant pastoralist narrative (Cardarelli, 2015; Manfredini, 2014).

Thorough studies of Copper Age economy are few in comparison to other time periods, although zooarchaeological evidence also indicates that the period was characterised by mixed-farming and the development of small-scale transhumant systems (Anzidei *et al.*, 2007, 2016; Barker, 1999; Cerilli, 2011; Tecchiati *et al.*, 2013). Palaeodietary studies on central Italian Copper Age groups show an overall reliance on terrestrial animal protein, although some exploitation of freshwater resources in the Marche (De Angelis *et al.*, 2019; Martinez-Labarga *et al.*, 2016). In Sardinia, reduced consumption of animal proteins (Lai, 2008, 2015) and the development of larger villages (Manunza *et al.*, 2014; Webster and Webster, 2017) over the Copper Age suggests regional variation in how these economic processes took place. It has also been argued that hunting of wild animals also increased in importance during the Copper Age, although more for the purposes of social prestige than subsistence (Robb, 1998, 2007). Faunal assemblages across northern Italy do show some continued exploitation of wild animals throughout the Copper Age (Tecchiati *et al.*, 2013), and recent genetic analysis of clothing from Ötzi the Iceman shows combined use of domesticated and wild animal materials (O'Sullivan *et al.*, 2016).

The social structure of the Italian Copper Age was long considered as a patriarchal warrior pastoralist society dominated by male symbolism (Puglisi, 1959; Trump, 1966a), comparable to the social organisation of modern pastoralist groups (Eneyew and Mengistu, 2013). Scholars have argued that the artefactual record for Copper Age Italy displays a systematic expression of gender, whereby typically male and female symbolism was used to explicitly state, reinforce and strengthen a binary gender ideology that was not otherwise present in the preceding Neolithic (Dolfini, 2004; Robb, 1994b; Whitehouse, 2001). Within this gender ideology, weapons primarily represented adult males, whilst females are usually represented by anatomical features (i.e. breasts) and items of personal adornment (Robb, 2009; Whitehouse, 1992, 2001).

The suggestion that explicit expressions of gender first emerged during the Copper Age has, almost exclusively, been explored through indirect archaeological, funerary and material evidence, where scholars have sought to simply equate biological sex with gendered artefact types. This is highly problematic given that the material record for the Copper Age central Mediterranean is extremely fragmented, and few studies have used methods in bioarchaeology as a means of exploring social change in Italian prehistory (Brown, 1998; Robb, 1997; Sparacello *et al.*, 2011). Social change in the Copper Age has also received much less dedicated research than that of the adjacent Neolithic and Bronze Age time periods. In general, discussions concerning the social structure and gender ideology of the central Mediterranean Copper Age are often included as a footnote in a larger Bronze Age story (Robb, 1994b; Whitehouse, 2001), which is symptomatic of the manner in which the time period has been approached and theorised – as a transitory phase between the Neolithic and Bronze Age.

2.4.1 Copper Age southern Italy

The Copper Age in southern Italy has historically been associated with the *Gaudo* culture in Campania and *Laterza* culture in Apulia and Basilicata (Cocchi Genick, 2009; Trump, 1966a). Until recently, the southern Italian Copper Age was entirely known from large *Gaudo* culture rock-cut tomb cemeteries, as at Pontecagnano (Bailo Modesti and Salerno, 1998), Eboli (Bailo Modesti and Salerno, 1995), Buccino (Holloway, 1976) and Paestum-Gaudo (Aurino, 2015), and the type-site necropolis of Laterza, Taranto (Biancofiore, 1967), with both *Gaudo* and *Laterza* being considered as contemporary.

Recent excavations have instead highlighted the complexities of the Copper Age in southern Italy, extending the distribution of *Gaudo* and *Laterza* ceramic styles to central Italy (Carboni and Anzidei, 2013; see Section 2.4.2) and as actually representative of chronologically discrete cultural horizons - *Gaudo* representing the Middle Copper age and *Laterza* representing the Later Copper Age (Aurino, 2013; Figure 2.3). The recent introduction of a new earlier *Taurasi* phase associated with cremation cemeteries in Campania (Passariello *et al.*, 2010), Apulia and Basilicata (Aprile *et al.*, 2013; Cazzella, 2012; Quarta *et al.*, 2014), further demonstrates the true complexity of the south Italian Copper Age. In Campania, *Gaudo* phase settlements on the fertile coastal plain north of Naples at Caivano and Afragola feature small groups of huts and show two successive phases of occupation separated by the Agnano 3 eruption horizon (Passariello *et al.*, 2010), with an apparent quick reoccupation of the area following the event. Later Copper Age *Laterza* activity in Campania sees variation in settlement location from valley bottoms and sides, to highland sites that appear to be related to the control of natural route ways, and persisting into the Early Bronze Age (Talamo, 2006). In the south-east, Copper Age activity on the Apulian Tavoliere was minimal and instead densities of Late Neolithic-Copper Age sites are known in the Murge Plateau (Fiorentino *et al.*, 2013), Basilicata and the Salento peninsula (Pacciarelli *et al.*, 2015). Recent excavations at Tegole have uncovered a small settlement of three or four ovoid huts, representing an important Copper Age presence on the western margin of the Tavoliere (Tunzi *et al.*, 2013, 2017).

2.4.2 Copper Age central Italy

The *Rinaldone* culture traditionally defined the entire central Italian Copper Age (Trump, 1966a), although recent research in Marche and southern Rome has shown the complex spatial and temporal relationship between the Copper Age in central and southern Italy (see Figure 2.3). In light of recent discoveries, the terminology has been revised and the central Italian Copper Age has been divided into three main clusters or ‘groups’ – the *Ponte San Pietro Group/Core Rinaldone Zone* (Viterbo area), *Camerano-Fontenoce Group* (Marche) and *Roma-Colli Albani Group* (southern Rome) (see Cocchi Genick, 2009, 2011a).

Named after the type-site discovered in 1903 at Montefiascone in Viterbo (Dolfini, 2004), the *Rinaldone* culture is entirely known from large rock-cut tomb cemeteries densely distributed on the border between Tuscany and Latium. The earliest *Rinaldone* rock-cut tomb cemeteries show a combination of both primary and secondary burial, but continued use of funerary sites into the 3rd millennium BC, as at Garavicchio (Dolfini, 2010), and into the 2nd millennium BC, as at Selvicciola (Petitti *et al.*, 2003), show increasing elaboration of secondary funerary rites (Todaro and Girella, 2013). The long use of distinctive *Rinaldone* style ceramics (Figure 2.3) suggest that the phase actually represents a so-called funerary *facies* (Dolfini, 2006b; Cazzella and Guidi, 2011).

Settlement evidence for the central Italian Copper Age varies considerably across the three clusters of activity. The *Ponte San Pietro* group on the Tuscany-Latium border still has no known settlements, in spite of an abundance of funerary sites (Negroni Catacchio *et al.*, 2016) and evidence for demographic expansion during this time (Palmisano *et al.*, 2017). Research in southern Rome has shown intensive activity in the area between the Tiber river and Colli Albani volcano, reshaping the entire Copper Age sequence for central-southern Italy (Anzidei *et al.*, 2007; Carboni and Anzidei, 2013; Forte and Medeghini, 2015). The sites of the *Colli Albani Group* show dense and stable settlement in southern Rome from the mid-4th to late 3rd millennia BC, alongside continuity in economy and burial traditions across the entire Copper Age sequence, from the earlier *Gaudo* phase, through the later *Laterza*, *Ortucchio* and Bell Beaker phases.

On the Adriatic coast of central Italy, evidence for Copper Age activity associated with the *Camerano-Fontenoce* group has been found along the narrow coastal plain surrounding Ancona and into the Apennines, with funerary sites situated towards the coast and settlement situated inland (Cazzella and Moscoloni, 2012b; Manfredini *et al.*, 2009). Funerary rites mirror that of the *Ponte San Pietro Group*, although higher representation of juveniles and articulated individuals are noted in the Marche cemeteries (Dolfini, 2006a; Silvestrini *et al.*, 2011) and some divergences in material culture have prompted much discussion on trans-Apennine similarities (Cazzella and Moscoloni, 2012b; Cazzella and Silvestrini, 2005; Dolfini, 2006b; Silvestrini *et al.*, 2004). In a summary article, Cazzella and Moscoloni (2012b) presented three possible hypotheses for the origin of these similar cultural and funerary traditions; 1) independent development in Tyrrhenian, central Italy; 2) independent development in Adriatic central Italy; or 3) parallel development, citing absence of sites between the two geographical areas. Large open-air villages are known in Marche at Conelle di Arcevia (Cazzella and Moscoloni, 1999) and Maddalena di Muccia at Macerata (Manfredini, 2014) and attest to the existence of stable settlements.

2.4.3 Copper Age northern Italy

The north Italian Copper Age has traditionally been defined by the *Remedello* culture (Barfield, 1971), which covered the Po Valley and was defined by a distinctive dagger type. As with elsewhere in Italy, systematic research over recent decades has shown that the archaeological record is considerably more varied (De Marinis, 1997). To the south of the Po river, inhumation cemeteries and settlements are found associated with the *Spilamberto Group* (Bagolini, 1981; Bertoldi *et al.*, 2012; Miari, 2014; Miari and Benazzi, 2018). To the north, the *Civate Group* is known from burials in caves and statue menhirs in the Alpine regions (Barfield, 1983), whilst cave burials are documented in Liguria.

Copper Age settlement in northern Italy appears on fluvial terraces and on the slopes of the pre-Alps, where multi-stratified sites demonstrate long occupation histories spanning the duration of the Copper Age, such as at Lovere-Colle del Lazzaretto and Monte Covolo in Lombardy (Baioni and Poggiani-Keller, 2013). Similarly long use of occupation sites occurs in the inner Alpine valleys, as at Latsch, Vinschgau (Festi *et al.*, 2011), which are exploited from the Late Neolithic onwards (Putzer *et al.*, 2016). Copper Age settlements also occur on the southern Po plain, with some focus on the margin with the Emilian Apennines (Berni *et al.*, 2011; Miari, 2014). In terms of burial, rock-cut tombs are entirely absent north of the Apennine mountains and instead inhumation burial is the norm in the Po Valley area, as at Remedello (Barfield, 1995; De Marinis, 1997), Spilamberto (Bagolini, 1981; Ferrari and Steffè, 1999) and Forlì-Celletta (Bertoldi *et al.*, 2012; Miari, 2014), whilst burial in caves is documented around the Alpine and Apennine regions and in Liguria (Barfield, 1983; for review see Barfield, 1986).

Perhaps of most significance for the north Italian Copper Age was the discovery of 'Ötzi' the Iceman, an exceptionally well preserved mummified middle-aged male found in association with his clothing and an extensive range of equipment (Barfield, 1994b). Found at high altitude in the Ötztal Alps along the Austrian-Italian border in 1991, systematic scientific analysis has been undertaken on every aspect of the mummy over the last three decades, providing an unprecedented - albeit singular - view into Copper Age lifestyle. Dating to 3400-3100 cal. BC, intensive research has shown that the Iceman likely died as the result of an arrow wound to his left shoulder following a violent incident (Gostner and Egarter Vigl, 2002; Nerlich *et al.*, 2003) and, whilst physically active (Ruff *et al.*, 2006a), lived with a number of physical ailments (Keller *et al.*, 2012; Maixner *et al.*, 2014, 2016; Seiler *et al.*, 2013; Zink *et al.*, 2019). A series of 61 tattoos across the mummy's body have been interpreted as serving a possible medicinal function due to their close proximity to areas of joint disease, perhaps representing a form of acupuncture or pain relief (Samadelli *et al.*, 2015).

The Iceman appears to have readily exploited both wild and domesticated resources, as documented by analysis of his clothing, which was comprised of wild and domesticated animal skins and plant matter (O'Sullivan *et al.*, 2016), and analysis of his stomach contents, which showed that his last meal consisted of fatty wild meat and cereals (Maixner *et al.*, 2018; Rollo *et al.*, 2002). Ancient DNA analysis has shown that Ötzi was genetically similar to Neolithic European and modern Sardinian populations (Coia *et al.*, 2016; Ermini *et al.*, 2008; Keller *et al.*, 2012). The Iceman's tool-kit, consisting of bone (Barfield, 1994b), flint (Wierer *et al.*,

2018) and copper tools (Artioli *et al.*, 2017), displays an extremely rich and vast array of personal items, the wealth of which has prompted an alternative interpretation that the remains of the Iceman represent a disturbed burial (see Vanzetti *et al.*, 2010). The Iceman's tool-kit also demonstrates exploitation of flint sources from across the northeast Italian Alps and copper ores from southern Tuscany, indicating that extensive trade networks existed during the Italian Copper Age (Artioli *et al.*, 2017; Wierer *et al.*, 2018). Whilst the singularity of the Iceman may mean he is not representative of the north Italian Copper Age, the opportunity to examine a single individual with the full suite of scientific methods available in bioarchaeology is certainly unparalleled in European prehistory.

2.4.4 Copper Age Sardinia

In Sardinia, the Early Copper Age *Sub-Ozieri/Ozieri II* and *Abealzu-Filigosa* phases show much continuity with the preceding Late Neolithic *Ozieri I* phase, as reflected in similarities in settlement patterns and burial practices (Lai, 2008; Melis, 2014; Webster and Webster, 2017). Marked changes in material culture, mortuary practices and settlement patterns instead occurred during the Late Copper Age *Monte Claro* phase. Although Late Neolithic and earlier Copper Age funerary monuments were reused throughout the *Monte Claro* phase, the Late Copper Age saw the development of new funerary monument types and existing sites were often elaborated with megalithic elements, as at Scab'e Arriu (Badas and Usai, 1988; Melis, 2014; Usai *et al.*, 2011). Large villages also began to emerge in the Late Copper Age, such as Monte Pranu which consisted of up to 60 dispersed huts (Manunza *et al.*, 2014), but substantial settlement sites are also known for the Late Neolithic (Melis, 2011). However, settlement in the *Monte Claro* phase is largely located on lowlands and hills, with a clear shift away from the coastal settings of the Neolithic and earlier Copper Age (Lilliu, 1963).

Interpreting Copper Age settlement patterns in Sardinia is problematic, as most sites are known from either surface features or find scatters, and hut forms are similar across the *Ozieri I* and *Abealzu-Filigosa* cultural horizons (Melis, 2000; Webster and Webster, 2017). Similarly, the chronology of the Sardinian Copper Age remains poorly defined, and adequate understanding of the period is hampered by a lack of radiocarbon dates (Melis, 2013; Melis *et al.*, 2007; see Figure 2.3). The economy of Early Copper Age Sardinia appears to have been predominately based on agro-pastoralism, in line with the wider central Mediterranean (Barker, 2005), but palaeodietary studies indicate an increased reliance on cereal agriculture and a shift away from pastoralism in the *Monte Claro* phase (Lai, 2015).

2.4.5 *Copper Age Sicily*

The Copper Age in Sicily is considered as emerging in the late 5th to early 4th millennia BC with 'proto-Eneolithic' rock-cut tomb cemeteries associated with the *San Cano-Piano Notaro* culture, such as Piano Vento (Castellana, 1995) and Scintilia (Gullì, 2014) in the south, and with the *Conca d'Oro* culture in the north (Tiné, 1960). Copper Age settlement in Sicily shows occupation of a variety of landscape locations, and as with adjacent areas of peninsular Italy, some continuity with the Late Neolithic and Early Bronze Age (Leighton, 1999). In general the period is characterised by a general expansion into the uplands (Leighton, 2005), apparent in both the earlier Copper Age, as at Fildidonna (Cazzella and Maniscalco, 2012a), and later Copper Age, as at Troina (Malone *et al.*, 2003) and Case Bastione (Giannitrapani *et al.*, 2014). In southeast Sicily, areas of dense Early Neolithic activity on the coastal planes surrounding Syracuse and Catania remain largely unused through the Copper Age (Leighton, 1999).

2.4.6 *Late Neolithic Malta – 'Temple Period'*

In the Maltese Islands, the 4th and 3rd millennia BC saw the rise of a sophisticated culture characterised by elaborate megalithic structures, art and complex ritual processes that expressed a strong local identity (Bonanno *et al.*, 1990; Trump, 2002). The sharp cultural discontinuity between the Early Neolithic (*Għar Dalam* and *Skorba* phases) and the 'Temple' Period has been the focus of much discussion (Trump, 2002), setting a prevailing theoretical framework that suggested increased isolation and insularity over time (Stoddart *et al.*, 1993; Trump, 1961), although this has been challenged elsewhere (Grima, 2002; Robb, 2001).

Malta remained culturally analogous to neighbouring Sicily and southern Italy throughout the Early and Middle Neolithic (Malone, 2003; Trump, 1966b). The *Żebbuġ* phase (ca. 3800-3400 cal. BC), which closely parallels the *San Cono-Piano Notaro* culture of Sicily (Barone *et al.*, 2010; Leighton, 1999), marks a final period of strong cultural equivalence with Sicily and the first emergence of distinctive megalithic architecture on the islands, before Malta's prehistory took a truly divergent course during the *Ġgantija* phase (ca. 3400-3000 cal. BC). By 3000 cal. BC, the Maltese Neolithic sequence concluded with a highly sophisticated final *Tarxien* phase (3000-2400 cal. BC) (Malone *et al*., 2009b; Sagona, 2015). The *Tarxien* phase is characterised by elaborate art, ranging from miniature figurines to large statues (Malone, 2008; Pace, 1996), and complex megalithic architecture and funerary hypogea (Evans, 1996; Malone, 2007).

The *Tarxien* phase appears to have been a period of accelerated landscape clearance (Carrol *et al.*, 2002; Schembri *et al.*, 2009) and soil degradation (French *et al.*, 2018) as a result of agricultural intensification, to which the Temples likely formed a focus (Stoddart *et al.*, 1993). Domestic evidence for the Temple Period in Malta is extremely scarce (Malone *et al.*, 2009a), in contrast with a wealth of megalithic ritual architecture. Aside from unconvincing arguments that subsidiary structures at megalithic sites represent huts (Sagona, 2015), only two Temple Period hut structures have been excavated on the island of Gozo (Malone *et al.*, 1988; Stoddart, 2014).

2.5 The Bell Beaker phenomenon in the central Mediterranean

An important, yet neglected, chapter of central Mediterranean prehistory is the spread of the Bell Beaker (*Campaniforme*) phenomenon to the central Mediterranean region. The introduction of this Pan-European phenomenon to the Mediterranean region prompted intermixing with local Copper Age ceramic styles and the Beakers are usually associated with influencing the succeeding Sardinian *Bonnanaro* (Melis, 2000, 2011) and north Italian *Polada* (Dal Santo *et al.*, 2014) Early Bronze Age material cultures. The Bell Beakers were mostly distributed across northern Italy, Sardinia and Sicily (Whitehouse and Renfrew, 1974) although excavations in the 1960s and 1970s extended the Beaker presence to central Italy (Ridgway, 1972). In central and southern peninsular Italy, the Beaker influence is often discussed with respect to intermingling with the local later Copper Age *Ortucchio* and *Laterza* ceramic styles (Carboni and Anzidei, 2013; Pacciarelli *et al.*, 2015). In Malta, similarities have also been drawn between Sicilian Bell Beaker ceramic motifs and the contemporary Early Bronze Age *Tarxien Cemetery* (pers. comm., Guillaine, J. 2018). The settlement record and economy of the central Mediterranean Bell Beakers remain poorly defined.

2.6 Postlude: the Bronze Age

The Italian Bronze Age is characterised by a gradual development towards social, economic and political complexity that ultimately led to state development in the Iron Age (Bietti Sestieri 2010; Pacciarelli 2000). The north Italian Early Bronze Age in the late 3rd to early 2nd millennia BC is represented by the *Polada* culture which saw dense settlement along the shores of the sub-Alpine lakes, and limited settlement on the Po Plain (Barfield, 1994a; Capuzzo, 2014; Nicolis, 2013). This was followed by a largescale shift in settlement activity to the central Po Plain during the 2nd millennium BC during the Middle Bronze Age with the rise of the *Terramare* system (Rondelli, 2008; Vanzetti, 2013). The *Terramare* settlements were planned villages of pile-built houses, serviced with drainage and enclosed within quadrangular banks (Bernabò Brea *et al.*, 1997; Pearce, 1998) that seem to have developed in conjunction with important technological and agricultural innovations and social change (Cardarelli, 2009).

However, the most important developments occurred in central Italy, where evidence for population increase and the emergence of city states led to a level of social and political complexity that was previously unseen in prehistoric Europe (Barker, 1999; Barker and Stoddart, 1994; Palmisano *et al.*, 2017, 2018; Stoddart *et al.*, 2019). Regarding economy, the Italian Bronze Age is generally characterised by mixed agriculture, but also evidence for continued development of specialised pastoral agriculture (Barker, 1981; 1999).

For the southern part of the central Mediterranean, the picture of the Bronze Age is one of complex regional diversity. In the south of the Italian peninsula, caves continued to be used for settlement, ritual and funerary purposes, whilst Early Bronze Age *Palma Campania* villages in Campania show lowland occupation and a reliance on ovicaprines, pig and cattle, alongside active food storage (Albore Livadie and D'Amore, 1980; Price, 2013). Larger sites such as Toppo Daguzzo (Basilicata) and La Starza (Campania) located between environmental zones on communication routes (Malone *et al*., 1994), and larger fortified and defended settlements at Roca Vecchia and Coppa Nevigata in Apulia (Alberti, 2013b) echo some of the developments seen further north. The Early Bronze Age of Sicily and the Aeolian Islands brought population increase and settlement expansion to defended sites (Malone *et al.*, 1994; but see Alberti, 2013a; Leighton, 2005).

On the Maltese Islands, the elusive Early Bronze Age *Tarxien Cemetery* phase marks a period of much reduced activity from the preceding Temple Period, but some degree of continuity in settlement (pers. comm., Malone, C. 2015). In Sardinia, the Bronze Age is defined by the *Nuragic* period which saw massive population increase and settlement expansion (Lilliu, 1963; Webster, 2015), demonstrated by the widespread distribution of some 7000 Nuraghe throughout the island. This eponymous architectural feature consisted of a large conical tower, with later Nuraghe featuring multiple towers and subsidiary structures (Melis, 2017). Parallel traditions to the Nuraghe occur in other western Mediterranean islands, such as the *Torre* of southern Corsica (Peche-Quilichini and Cesari, 2017), *Sesi* in Pantelleria (Orsi, 1899) and *Talayots* on the Balearic Islands (Gili Suriñach *et al.*, 2006). In the Maltese Islands, villages associated with the Middle Bronze Age *Borġ in-Nadur* phase were also located within large walled enclosures (Evans, 1971; Tanasi and Vella, 2011). Towards the end of the Bronze and Iron Ages, the central Mediterranean saw the development towards social and political complexity among indigenous pre-Roman Iron Age groups, that was most evident in central Italy, alongside the increasing prevalence of external contacts with Greek and Phoenician colonists in the south of Italy, Sicily and Sardinia.

2.7 Conclusion

This chapter has provided an overview of the later prehistory of the central Mediterranean, illustrating the richness and variability of the region's archaeological record. In a broad sense, the entire central Mediterranean region underwent the same fundamental transformations during the 4th and 3rd millennia BC, that saw a shift to dispersed settlement, and the creation of delineated ritual or funerary spaces in the landscape, alongside the widespread adoption of communal burial practices. However, these wholescale changes manifested themselves differently in some parts of the central Mediterranean (Table 2.1, see next page).

Regions such as Sardinia and the Maltese Islands have demonstrably insular archaeological records, reflected in both their material culture, whilst the central-southern Italian peninsula shows some homogeneity in the archaeological record (Table 2.1). The cultural uniqueness of Sardinia and the Maltese Islands during the 4th millennium BC is perhaps most clearly viewed through the architectural and funerary traditions which developed on both islands at this time, but also permeated into differences in settlement and economy. The justification of this phenomenon has been discussed at length for the Maltese Islands, where the archipelago's archaeological singularity has been argued as arising from increased isolation (Stoddart *et al.*, 1993) or as a manifestation of a strong regional identity (Robb, 2001). This is not to say that the remainder of the central Mediterranean was devoid of cultural uniqueness or regional variation during the Copper Age, as distinctive regional traditions existed throughout the Italian peninsula (see Robb, 2001), and research over the past decade has fundamentally changed our understanding of the traditional Copper Age cultures of the region. Ultimately, the Bronze and Iron Ages led to the gradual development of the social and political structures that lay the foundation for the modern Western culture.

Table 2.1: Summary of main changes in settlement, economy and funerary practices in the central Mediterranean between the Early-Middle Neolithic and the Late Neolithic-Copper Age.

Period	Southern Italy	Central Italy	Northern Italy	Sardinia	Maltese Islands
Early-Middle Neolithic	**Settlement:** Large villages central to society, flat coastal plains **Burial/Ritual:** Within domestic areas, use of 'cult caves' **Economy:** Reliance on cereals and dominance of ovicaprines	**Settlement:** Valley bottoms, near water sources. Record largely dominated by so-called *fondi di capanna* **Burial:** Limited burial evidence, burial within settlement/domestic contexts **Economy:** Reliance on cereals and ovicaprines	**Settlement:** Limited settlement evidence on Po Valley, largely represented by so-called *fondi di capanna,* settlement in caves in Liguria **Burial:** Caves, domestic, cist cemeteries **Economy:** Pastoralism in Liguria, reliance on cereal agriculture and increased reliance on cattle in wider northern Italy	**Settlement:** Initial settlement in caves, coastal areas, **Burial:** Caves, small rock-cut tombs **Economy:** Cereal, ovicaprines, cattle, exploitation of endemic microfauna during earliest Neolithic, and obsidian resources	**Settlement:** Small villages, similar to Sicily/S. Italy **Burial:** In settlements/domestic contexts(?), **Economy**: Cereal crops, ovicaprines, some cattle
Late Neolithic-Copper Age	**Settlement:** Upland areas, coastal areas, abandonment of previously inhabited areas (i.e. Tavoliere) **Burial:** Discrete cemeteries, cist burials, rock-cut tomb and cremation burial in Copper Age **Economy:** Mixed agriculture?	**Settlement:** Regional variation, small villages, development of larger villages on Adriatic coast **Burial:** Rock-cut tomb cemeteries, caves, settlement cemeteries, **Economy:** Increasing dominance of pastoralism(?), some reliance on marine resources on Adriatic coast	**Settlement:** Exploitation of inner Alps and upland areas **Monuments**: Statue stelae, open air 'cult sites' **Burial:** Inhumation cemeteries, caves, mortuary houses/cremation **Economy:** Mixed agriculture, continuation in pastoralism?	**Settlement:** Dispersed settlement throughout island, development of large villages in Late Copper Age **Monuments:** Pyramid (i.e. Monte d'Accoddi), statue stelae **Burial:** Continued use of funerary hypogea ('*domus de janas*'), megalithic tombs, caves **Economy:** No increased reliance on pastoralism	**Settlement:** Small dispersed huts(?) **Monuments:** Elaborate megalithic architecture, sophisticated megalithic art **Burial:** Funerary hypogea, rock-cut tombs, adapted caves(?) **Economy:** Agricultural intensification(?) Limited resources and land exhaustion

3 MATERIALS

3.1 Introduction

The following chapter provides an overview of the skeletal material analysed in this thesis, describing the chronology, geographic and archaeological context of each archaeological site. Given the geographical and temporal span of this study, as well as the range of archaeological cultures represented by the research materials, it is important to provide adequate context for each site. In addition to providing the contextual details for primary data, this chapter also introduces the comparative data that have been isolated from the Ruff (2018c) European Database and used in the analysis of long-term trends in body size and long bone morphology.

The analysis of each site was undertaken in accordance with a careful sampling strategy that accounted for the chronological and archaeological context of each site. The fragmentary nature of the archaeological record in the central Mediterranean meant it was necessary to create composite samples consisting of material from several sites (i.e. southern and northern Italian Neolithic and Copper Age central Italy). Other samples are composed of complex commingled assemblages that required a considered sampling strategy and approach (i.e. the Brochtorff-Xagħra hypogeum). In this chapter, the overall sampling strategy and chronology of each sample are outlined, before individual sites are described according to the geographic regions defined in Figure 2.2.

3.1.1 Overview of research materials

A total of 17 collections of human remains from across the central Mediterranean were analysed and included in this study (Figure 3.1). Firstly, the sampling strategy was directed towards gathering a large data set of coeval individuals for the Neolithic and Copper Age periods so as to explore temporal trends in body size and long bone morphology. Secondly, sampling was also aimed at gathering representative material from both archaeologically and geographically distinct contexts within the central Mediterranean in order to investigate spatial trends within the two time periods.

The individual collections vary in terms their size and state of preservation, ranging from single inhumations to large assemblages of disarticulated and fragmented human remains (Appendix A Table A.1; Table 3.1). In some cases, individuals from archaeologically and geographically related contexts were grouped together to create composite samples (Table 3.1) in order to increase sample size and statistical robusticity. For the Neolithic period, a composite sample of 31 individuals from the Finale region of Liguria (Figure 3.1, 2-6) represents the north Italian Neolithic, whilst a collection of 15 articulated individuals from Apulia and Basilicata (Figure 3.1, 10-14) represents the southern Italian Neolithic. A composite sample of 36 articulated individuals from two Early Copper Age sites in central Italy (Figure 3.1, 8-9) was created to facilitate comparative analysis with Neolithic groups. As most skeletal assemblages for the Italian Copper Age are commingled and highly fragmented, the central Italian Copper Age sample provides an extremely rare opportunity to explore detailed patterns in body size and long bone robusticity. The age estimates and sex determinations for all articulated skeletons were provided by curators and were acquired using standard methods (Buikstra and Ubelaker, 1994; White *et al.*, 2011).

This study set out to collect data from Neolithic and Copper Age skeletal assemblages from across all geographic areas of the central Mediterranean, thus ensuring that region specific diachronic trends could be explored. Whilst every attempt was made to achieve this, it was not possible to attain complete coverage of all regions and time periods within the scope of this PhD project. An extensive literature review was undertaken at the beginning of this project in order to ascertain the extent of existing skeletal material for the Neolithic and Copper Age periods. Robb's (1994a) study of Neolithic burial in Italy provided a useful resource for assessing the extent of existing Neolithic skeletal assemblages in the region. No such comprehensive list of existing skeletal material has been made for the central Mediterranean Copper Age (but see Leonini and Sarti, 2006; Vargiu *et al.*, 2009) and it was therefore necessary to create a database of potential study sites. Table A.9 (see Appendix A) contains a list of Copper Age skeletal assemblages that were actively considered for this study, with details of their curatorial status and reasons for not being included in the final study. Concerted efforts were made to contact curators, negotiate access to research materials and trace lost assemblages of skeletal remains over the first two years of this PhD project (from September 2015-September 2017).

Whilst the list presented in Table A.9 does not constitute a complete record of surviving skeletal material from the central Mediterranean Copper Age, it does represent an important foundation for future scholars seeking to undertake bioarchaeological research in the region. The extensive fieldwork undertaken as part of this project also presented opportunities to visit and view prospective assemblages and assess their level of preservation and suitability for future bioarchaeological research.

Figure 3.1 – Location map of sites studied (numbers correspond to Table 3.1).

Table 3.1: Study sites listed by geographical region (see Figure 3.1).*

No.	Site	Country	Region	Sample name[a]	Sample preservation[b]	Institution	Curator
1	Saint-Martin-de-Corléans	Italy	Valle d'Aosta	Alpine Beaker	Commingled, fragmented	Sop. Aosta	Dr. L. Raiteri
2	Arene Candide	Italy	Liguria	Neolithic N. Italy	Articulated	Museo Finale & Genova	Dr. Arobba/Dr. Garibaldi
3	Arma dell'Aquila	Italy	Liguria	Neolithic N. Italy	Articulated	Museo Finale	Dr. D. Arobba
4	Grotta Pollera	Italy	Liguria	Neolithic N. Italy	Articulated	Museo Finale & Genova	Dr. Arobba/Dr. Garibaldi
5	Bergeggi	Italy	Liguria	Neolithic N. Italy	Articulated	Museo Genova	Dr. P. Garibaldi
6	Pian del Ciliegio	Italy	Liguria	Neolithic N. Italy	Articulated	Museo Finale	Dr. D. Arobba
7	Forlì-Celletta	Italy	Emilia-Romagna	Copper Age Po Valley	Articulated, fragmented	Uni. Venezia	Prof. F. Bertoldi.
8	Fontenoce-Recanati	Italy	Marche	Copper Age c. Italy	Articulated	Sop. Tuscany	Dr. E. Pacciani
9	Ponte San Pietro	Italy	Tuscany	Copper Age c. Italy	Articulated	Uni. Firenze	Prof. J. Moggi-Cecchi
10	Masseria Candelaro	Italy	Apulia	Neolithic S. Italy	Articulated, fragmented	Museo Pigorini	Dr. L. Bondioli
11	Fonteviva	Italy	Apulia	Neolithic S. Italy	Articulated, fragmented	Duckworth	Prof. M. Lahr
12	Ripa Tetta	Italy	Apulia	Neolithic S. Italy	Articulated	Uni. Pisa	Mr. Fulvio Bartoli
13	Trasano	Italy	Basilicata	Neolithic S. Italy	Articulated	Uni. Pisa	Mr. Fulvio Bartoli
14	Samari	Italy	Apulia	Neolithic S. Italy	Articulated, fragmented	Uni. Pisa	Mr. Fulvio Bartoli
15	San Benedetto-Iglesias	Italy	Sardinia	Neolithic Sardinia	Commingled, fragmented	Uni. Cagliari	Prof. E. Marini
16	Sacaba'e Arriu	Italy	Sardinia	Copper Age Sardinia	Commingled, fragmented	Sop. Cagliari	Dr. O. Fonzo
17	Xagħra hypogeum	Maltese Islands	Gozo	Late Neolithic Malta	Commingled, fragmented	NMA, Valletta	Ms. S. Sultana

**Individual details on number of individuals and skeletal elements from each site are presented in Appendix 1 Table A1.1. The lists of articulated individuals within each assemblage are included in Appendix 1 in Tables A1.3-A1.7.*

[a] Sample name corresponds to how the site is referred to throughout the analysis, [b] See Chapter Four, Table 4.1.

3.1.2 Chronology of research materials

The chronological spread of the assemblages is limited to two clusters spanning the 6th-5th millennia BC and the 4th-3rd millennia BC (Figure 3.2). These two timeframes represent the Early-Middle Neolithic and Copper Age (Figure 3.2; Table 3.2), thus enabling diachronic comparisons between the two time periods to be made. One exception is Sardinia, where very little Early Neolithic skeletal material survives and therefore a Late Neolithic assemblage was included. The majority of assemblages have been radiocarbon dated, therefore providing a robust chronological framework that enables confident spatial and temporal comparisons to be made. In total, 34 of the articulated individuals analysed in this study have been directly radiocarbon dated (Table 3.2). An additional 22 radiocarbon dates associated with the larger commingled assemblages are included in Appendix A Table A.2 and represented in Figure 3.2. Date ranges for the Ligurian Caves, Brochtorff-Xagħra hypogeum and Saint-Martin-de-Corléans are made on the basis of unpublished radiocarbon dates (pers. comm., McLaughlin, T.R. 2018; pers. comm., Sparacello, V. 2018; pers. comm., Raiteri, L. 2017) that are not reported in full here.

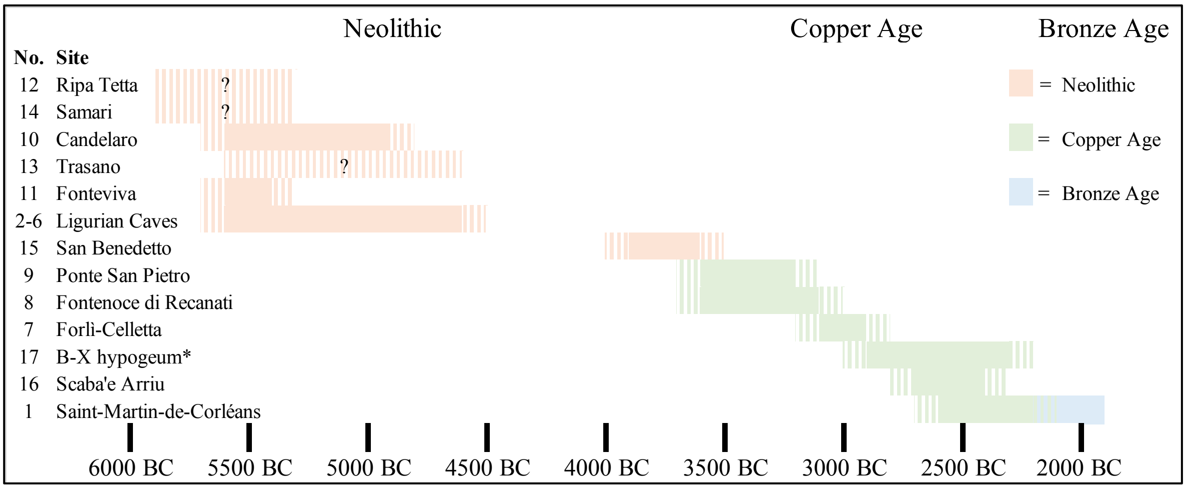


Figure 3.2 – Absolute chronology of sample materials. Chronological ranges for Trasano, Ripa Tetta and Samari are approximate relative date ranges. Date ranges for the Ligurian caves (pers. comm., Sparacello, V. 2018), Brochtorff-Xagħra hypogeum (pers. comm., McLaughlin, R. 2018) and Saint-Martin-de-Corléans (pers. comm., Raiteri, L. 2017) are based on unpublished dates. Numbers correspond to Figure 3.1 and Table 3.1.

Table 3.2: Summary of published direct dates on human bone from analysed individuals. Unpublished dates, not included here, exist for the Ligurian and Maltese samples, and are instead represented in Figure 3.2 (see Appendix A Table A.2 for list of associated dates for commingled assemblages).

Site	Sample ID	Lab code	^{14}C Age (BP)	Cal. BC. (95.4%)*	Reference
Masseria Candelaro	Pozzo P2,	OxA-12063	6601 ± 37	5616-5485	Cassano & Manfredini, 2005
Fonteviva	42.5.6	SUERC-77406	6594 ± 23	5566-5589	This study
Fonteviva	42.5.7	SUERC-77407	6570 ± 23	5560-5479	This study
Masseria Candelaro	Fossato F, St.6	OxA-3685	6510 ± 45	5557-5371	Cassano & Manfredini, 2005
Masseria Candelaro	45c, T12	OxA-10013	6450 ± 50	5486-5321	Cassano & Manfredini, 2005
Masseria Candelaro	Fossato F, T1	OxA-3683	6200 ± 95	5367-4858	Cassano & Manfredini, 2005
Arma dell'Aquila	AQII (Richard 1)	OxA-V-2365-36	6318 ± 33	5361-5220	Biagi & Starnini (2016)
Arma dell'Aquila	AQIII (Richard 2)	OxA-V-2365-35 GrA-38258	6155 ± 34 6125 ± 35	5208-5003	Biagi & Starnini (2016)
Arma dell'Aquila	AQV	OxA-V-2365-324	6118 ± 33	5208-4956	Biagi & Starnini (2016)
Arma dell'Aquila	AQI(Zambelli 1)	OxA-V-2365-37 GrN-17730	5804 ± 33 5800 ± 90	4724-4552	Biagi & Starnini (2016)
Fontenoce-Recanti	T1.1	LTL035A	4882 ± 61	3798-3523	Cazzella & Silvestrini 2005
Fontenoce-Recanti	T14.1	LTL166A	4897 ± 40	3768-3637	Cazzella & Silvestrini 2005
Ponte San Pietro	T21 IV.1bis	OxA-18217	4872 ± 35	3748-3537	Dolfini, 2010
Ponte San Pietro	T 7 VIII.1	OxA-18215	4794 ± 33	3648-3521	Dolfini, 2010
Ponte San Pietro	T23 XII.1	OxA-18275	4757 ± 30	3639-3383	Dolfini, 2010
Fontenoce-Recanti	T3.6	LTL162A	4724 ± 50	3636-3373	Cazzella & Silvestrini 2005
Ponte San Pietro	T21 IV.1	OxA-18216	4725 ± 33	3635-3376	Dolfini, 2010
Fontenoce-Recanti	T18.1	OxA-18287	4704 ± 30	3631-3372	Dolfini, 2010
Fontenoce-Recanti	T8.1	OxA-18283	4692 ± 31	3628-3371	Dolfini, 2010
Fontenoce-Recanti	T20.1	OxA-18289	4682 ± 31	3625-3369	Dolfini, 2010
Fontenoce-Recanti	T11.1	OxA-18284	4661 ± 30	3519-3366	Dolfini, 2010
Ponte San Pietro	T25 XI.1 F	OxA-18277	4555 ± 32	3484-3104	Dolfini, 2010
Fontenoce-Recanti	12.2	LTL165A	4525 ± 45	3368-3091	Cazzella & Silvestrini 2005
Fontenoce-Recanti	19.1	LTL168A	4513 ± 35	3356-3097	Cazzella & Silvestrini 2005
Forlì-Celletta	T75	?	4466 ± 40	3347-3018	Miari 2014
Forlì-Celletta	T47	?	4249 ± 50	3010-2666	Miari 2014
Forlì-Celletta	T42	?	4189 ± 45	2896-2631	Miari 2014
Forlì-Celletta	T64	?	4158 ± 50	2886-2584	Miari 2014
Xaghra hypogeum	CX799	OxA-3571	4080 ± 65	2871-2476	Malone *et al*. 2009
Xaghra hypogeum	CX1206	SUERC-4389	4035 ± 35	2834-2471	Malone *et al*. 2009
Xaghra hypogeum	CX960	SUERC-4391	3910 ± 40	2550-2234	Malone *et al*. 2009
Xaghra hypogeum	CX1241	SUERC-4390	3920 ± 35	2547-2293	Malone *et al*. 2009

*Calibrated using OxCal v4.3.2 (Bronk Ramsey, 2017) and IntCal13 (Reimer *et al*., 2013)

3.2 Malta

3.2.1 The Brochtorff-Xagħra hypogeum (Iċ-Ċirku tax-Xagħra/Xagħra Circle)

The Brochtorff-Xagħra hypogeum is a large multi-phase Late Neolithic mortuary complex situated on the Xagħra plateau, Gozo, in the Maltese Islands (Figure 3.1, no. 17). Located near to the Ġgantija and Santa Verna megalithic complexes, the site forms a part of a larger ritual landscape (Grima *et al.*, 2009). The main features of the site are the large *Tarxien* phase hypogeum (Stoddart *et al.*, 2009b) and an earlier double chambered rock-cut tomb that was previously associated with the early 4th millennium BC *Żebbuġ* phase (Malone *et al.*, 1995, 2009d), but is now understood to date to the *Ġgantija* phase (Malone *et al*., 2019a). Later occupation of the site is also evident through the presence of surface remains associated with the Early Bronze Age *Tarxien Cemetery* phase (Cutajar *et al.*, 2009). A megalithic stone circle surrounded the site at ground surface during the Temple period, although little now remains of this structure. The main period of use at the site was during the *Tarxien* phase (2900-2350 cal. BC; Table 3.2; Figure 3.2), when the hypogeum was the setting of a complex set of funerary rites, where skeletal material was deliberately disarticulated and dispersed around the hypogeum in a structured and ritualised manner (Malone and Stoddart, 2009; Parkinson *et al.*, 2015). Located within a natural cave system, the hypogeum was elaborated with megalithic architecture and periodically restructured. The combination of these site formation processes and the funeral rituals performed on site resulted in the formation a large commingled and highly fragmentary skeletal assemblage.

Osteological analysis of the Xagħra assemblage has shown evidence for an increase in skeletal indicators of stress within the later deposits of the site, particularly context 783 which is characterised by high incidences of pathology (Stoddart *et al.*, 2009a). Preliminary palaeodietary analysis using stable isotopes suggests that the Late Neolithic population of Gozo relied on terrestrial resources (Richards *et al.*, 2001). The human remains from the Brochtorff-Xagħra hypogeum are currently undergoing renewed study as part of the FRAGSUS ERC project (PI: Prof. Caroline Malone) that is undertaking ancient DNA, extensive radiocarbon dating, stable isotope analysis, taphonomic analysis and documentation of palaeopathology, alongside reinvestigation of the sites archive using Geographic Information Systems (Malone *et al.*, 2019; Stoddart, 2014).

The complexities of the Xagħra assemblage thus required a targeted sampling strategy. Sampling was directed towards three articulated individuals from contexts 799, 960 and 1241, in addition to three large commingled mortuary deposits (783, 1206 and 1268). Contexts 1206 and 1268 from the 'Shrine' area were primarily sampled because they contained high frequencies of humeri, femora and tibiae, but also because they presented the clearest example of a stratified sequence within the site (Stoddart, Malone, *et al.*, 2009).

3.3 Sardinia

3.3.1 San Benedetto-Iglesias (Tomb II)

Tomb II from the rock-cut tomb necropolis of San Benedetto-Iglesias is a vitally important site for the bioarchaeology and chronology of the Sardinian Late Neolithic. The partially destroyed site was discovered in 1961 during agricultural developments in the mountainous region of San Benedetto (Atzeni, 2001; Maxia and Atzeni, 1964), south-west Sardinia (Figure 3.1 no. 15). The site was at an approximate altitude of 500m ASL although its exact location is now unknown (Lai, 2008). The small *domus de janas* style tomb was part of a larger necropolis of five to six tombs and consisted of three sealed chambers centred around a central area. The site is associated with the Late Neolithic *Ozieri* phase and is radiocarbon dated to the first half of the 4th millennium BC (Floris, 2001; Lai, 2009; Melis, 2013) (Figure 3.2; Appendix A Table A.2). In a re-evaluation of the chronology of the Late Neolithic and Copper Age of Sardinia, Melis (2013) assigned the San Benedetto tomb to *Ozieri I* phase. An MNI of 35 individuals was estimated for the site by Germanà (1995), with the small assemblage largely consisting of isolated long bones and crania (Sarigu *et al.*, 2016). No substantial skeletal assemblage for the Sardinian Early-Middle Neolithic survives (Sanna, 2006), so the assemblage from San Benedetto-Iglesias is of great importance and represents the only securely dated collection of human remains for the *Ozieri I* phase. Other large collections assigned to the *Ozieri I* phase on the basis of cultural material from Is Aruttas (Cabras) and Lu Muccioni (Alghero) (Germanà, 1995) have since yielded later Bronze Age dates (Lai, 2008). Previous osteological analysis of the San Benedetto assemblage has been descriptive in nature, comprising of osteometric analysis of the crania and long bones (Germanà, 1995) and descriptions of non-metric traits and pathologies (Floris, 2001). Recent research however has highlighted the importance of the San Benedetto assemblage, drawing it into broader comparative studies on palaeodiet (Lai, 2008, 2015) and stature (Martella *et al.*, 2016) in Sardinian populations.

3.3.2 Scaba'e Arriu

The small multiphase *domus de janas* of Scaba'e Arriu, Siddi, is situated on the central Campidano plane of south-west Sardinia (Figure 3.1, no. 16). The site was excavated in 1983 and revealed two commingled burial assemblages radiocarbon dated to the Early and Late Copper Age (Badas and Usai, 1988; Lai *et al.*, 2011; Usai *et al.*, 2011) (Appendix A Table A.2). The site consists of a small burial chamber accessed through an antechamber and was likely constructed during the Late Neolithic *Ozieri I* phase and continued in use into the early 3rd millennium BC during Early Copper Age *Abealzu-Filigosa* phase, before it was structurally adapted and reused in the mid-3rd millennium BC during the Late Copper Age *Monte Claro* phase. During this later phase, earlier internments were cleared and deposited on the floor of the antechamber and newly constructed external megalithic corridor. As a result, the Early Copper Age *Abealzu-Filigosa* assemblage is highly fragmented and characterised by degraded cortical surface and was excluded from the analysis of long bone cross-sectional geometry. An

MNI of 99 (9 infants, 6 juveniles, 10 young adults, 6 mature adults, 12 old adults and 56 individuals of undetermined age) was established for the *Abealzu-Filigosa* phase assemblage (Lai *et al.*, 2011). The *Monte Claro* assemblage is much better preserved and was suitable for analysis of long bone cross-sectional geometry. The *Monte Claro* layers contained a collective burial assemblage of 44 individuals (6 infants, 8 juveniles, 4 young adults, 2 mature adults and 17 old adults) (Lai *et al.*, 2011) and also featured a *pithos* style burial within a ceramic vessel, containing the commingled remains of two adults and a juvenile (Badas and Usai, 1988; Usai *et al.*, 2011; Webster and Webster, 2017). A programme of bioarchaeological research and radiocarbon dating has been undertaken on the Scaba'e Arriu assemblages over the last two decades (Chilleri *et al.*, 2012; Lai, 2008; Lai *et al.*, 2011). Lai *et al.'s* (2011) and study on human and animal stable isotopes from Scaba'e Arriu demonstrated decreased consumption of animal proteins and dietary variation in the *Monte Claro* sample, correlating with broader trends observed across the Sardinian Neolithic, Copper Age and Bronze Age (Lai, 2015). Palaeopathological analysis of the assemblages observed high incidences of dental wear and abscesses, as well as a mandible featuring a granuloma associated with an embedded obsidian arrowhead (Lai *et al.*, 2011) and multiple cranial trepanations (Chilleri *et al.*, 2012).

3.4 Northern Italy

3.4.1 The Ligurian Caves

An important aspect of this research is the inclusion of a large sample of Neolithic individuals from Finale Ligure, Liguria, in northern Italy (Figure 3.1, no. 2-6). The composite sample is comprised of a mixture of articulated individuals and disarticulated isolated skeletal elements from across seven cave sites (Table 3.1; see Appendix A Table A.1 and Table A.3) which lie within a 10km radius. The majority of the burials from the Ligurian caves have previously been ascribed to the Middle Neolithic *Vasi Bocca Quadrata* (VBQ or 'Squared-Mouthed' pottery) culture dated to 4800-4200 cal. BC, although recent radiocarbon dating has demonstrated the long use of cave sites from the earlier Neolithic *Ceramica Impressa* to Byzantine periods (Sparacello *et al.*, 2019; pers. comm., Sparacello, V. 2018). The site of Arene Candide is also well known for its Upper Palaeolithic Gravettian burial (Pettitt *et al.*, 2003) and Epigravettian necropolis (Formicola *et al.*, 2005; Sparacello *et al.*, 2018a). The Neolithic burials typically consist of single crouched inhumations laying on the left side of the body within stone lined cists.

The Neolithic burials from Liguria have received much dedicated study over the past 60 years (Canci and Formicola, 1997; Formicola, 1986, 1997; Formicola *et al.*, 1987; Francalacci, 1989; Marchi and Sparacello, 2013; Parenti and Messeri, 1962; Sparacello *et al.*, 2016, 2017a). The cross-sectional geometry of the long bones of Neolithic individuals from Liguria have previously been extensively researched in a series of landmark studies which primarily demonstrated increased lower limb robusticity similar to that of highly mobile hunter-gather groups (Marchi *et al.*, 2006, 2011; Sparacello and Marchi, 2008). Recently, the relationship between tuberculosis and diaphyseal atrophy (wasting of bone tissue) was investigated in two Neolithic individuals from Liguria (Sparacello *et al.*, 2016). One of the individuals, an adult female from Arma dell'Aquila (AQ1), displayed skeletal signs of tuberculosis but had levels of long bone robusticity that were within in the normal range of variation for Ligurian Neolithic adults and therefore included in the analysis in this thesis.

The inclusion of the Ligurian sample in this research serves a dual purpose, in that the present study adds further regional context to the initial studies, which were based on comparisons with central European Copper Age data, but also because the well-studied samples act as an important reference point for the wider comparative analysis. Furthermore, the lack of southern Italian Neolithic individuals available for study (see Section 3.6) further emphasises the importance of the Ligurian sample in investigating overall temporal trends between the Neolithic and Copper Age. The Ligurian sample is comprehensively discussed elsewhere (Sparacello, 2013; Sparacello and Marchi, 2008; Sparacello *et al.*, 2016) and is currently the subject of renewed bioarchaeological analysis under the BUR.P.P.H. project (PI: Vitale Sparacello) which is examining ancient palaeopathology, 3D imaging, dietary stable isotopes, dental morphology and funerary taphonomy, alongside an extensive programme of radiocarbon dating. In particular, this new programme of research has begun to refine the chronological attribution of many of the "Neolithic" Ligurian burials, showing that some individuals are considerably earlier and later in date than previously thought (Biagi and Starnini, 2016; Sparacello *et al.*, 2019; pers. comm., Sparacello, V. 2018). Skeletons that were included in the original studies of skeletal biomechanics in Neolithic Liguria (Marchi, 2008; Marchi *et al.*, 2006, 2011; Marchi and Sparacello, 2013; Sparacello and Marchi, 2008; Sparacello *et al.*, 2011) that have since been demonstrated as dating to post-Neolithic time periods were removed from the analysis presented in this thesis. 3D scan data for some of the Ligurian Neolithic long bones were kindly shared by Vitale Sparacello and members of the BUR.P.P.H project.

3.4.2 Saint-Martin-de-Corléans (Tomb II)

The extensive multiphase site of Saint-Martin-de-Corléans is located in the semi-autonomous region of Valle d'Aosta in the Italian Alps (Figure 3.1, no. 1). The site was almost continuously occupied from the Middle Neolithic to modern periods although is most well-known for its

Copper Age and Early Bronze Age phases, when the site was used as a ceremonial area from 2900-2500 cal. BC, before being transformed into a megalithic funerary complex associated with the Bell Beaker phenomenon from 2700-1600 cal. BC. The site has strong parallels with Sion-Petit Chasseur, Switerzland, which lies 55km north of Saint-Martin-de-Corléans across the Swiss-Italian Alps (De Marinis, 1997). The archaeological and bioarchaeological research on Saint-Martin-de-Corléans is at present largely unpublished, although is summarised by Poggiani-Keller *et al.* (2016).

The earliest evidence for human activity on site dates to the mid to late 5th millennium BC in the form of Middle Neolithic plough marks and a later series of large NE-SW orientated pits, containing querns and large quantities of seeds (Poggiani-Keller *et al.*, 2016). Mezzena (1997) interpreted these early features as ritual, rather than agricultural, in nature, owing to their similar orientation to the later ceremonial and funerary structures. By the 3rd millennium BC, the site was transformed into a ceremonial and funerary complex, and from 2900-2500 cal. BC, a series of 24 timber posts were erected in a NE-SW orientation, followed by the erection of a series of over 40 statue stelae and menhirs in an identical orientation. During erection of the final stelae, the site was transformed into a megalithic funerary complex. The megalithic phase of the site (2700-1600 cal. BC) consists of seven tombs of varying types and size, ranging from small cists to larger circular tumuli, with later tombs reutilising stelae in their construction.

The main feature of the megalithic phase is a large dolmen (Tomb II) situated on a large triangular platform. Tomb II was used for collective burial throughout the Late Copper Age and Early Bronze Age, and contained a commingled assemblage of 39 individuals, with both inhumation and cremation burials (Marongiu *et al.*, 2011). Whilst all ages and both sexes are represented, a predominance of male individuals has been suggested as evidence of intentional selection. Analysis of all 66 individuals from the site is currently underway and has consisted of a programme of radiocarbon dating and studies relating to palaeodiet, population affinity and palaeopathology. Analysis of dental non-metric traits has suggested close biological affinity between the Saint-Martin-de-Corléans and Sion-Petit Chasseur groups. Stable isotope analysis of 45 individuals from across the site shows a largely carnivorous diet, with no age or sex-based differences. Three incidences of trepanation also occurred in Tomb II (Marongiu *et al.*, 2011; Piombino-Mascali *et al.*, 2006). Within the scope of this research, the Saint-Martin-de-Corléans sample represents an outgroup in that it is associated with both an environmentally and archaeologically distinct context and provides an opportunity to consider the Bell Beaker phenomenon, drawing the research into a wider European framework.

3.4.3 Forlì-Celletta dei Passeri

The large Copper Age necropolis of Forlì-Celletta was discovered in 2009 during the construction of a new prison on the outskirts of Forlì, Emilia-Romagna (Figure 3.1, no. 7). The partial excavations throughout 2009 and 2010 revealed 75 trench tombs distributed over an area of 5000 m^2, with the easternmost extent remaining unexplored (Miari, 2014). Prior to excavation the area was intensively cultivated resulting in the loss of superficial archaeological features, which along with waterlogging of the burials during excavation, resulted in increased friability and fragmentation of the human remains. The graves typically contained a single inhumation placed within a large cut, although many burials were disturbed either through the placement of later internments or the complete removal or manipulation of selected skeletal elements as part of complicated post-depositional processes (Bertoldi *et al.*, 2012; Miari, 2014). This combination of factors has resulted in an assemblage of highly fragmented and friable partially articulated individuals with variable element representation. The presence of post-holes surrounding grave cuts and the absence of intercutting between individual graves (with the exception of tombs 58 and 59) suggests the individual tombs were marked with visible above ground structures (Miari, 2014). The funerary assemblage usually comprised a small ceramic vessel placed at the foot of the individual, typical of the *Gruppo Spilamberto* (Bagolini, 1981; Ferrari and Steffè, 1999; Miari and Benazzi, 2018), although a smaller number of tombs contained flint arrow heads (23/75), copper axes (6/75) and *Remedello* type daggers (6/75) and a halberd. Osteological analysis of the skeletal assemblage is still underway, but has been reported in summary by Bertoldi *et al.* (2012) and consists of 40 adults (18 males, 7 females and 15 undetermined) and 10 juveniles, with a complete absence of individuals under the age of three. Of 12 individuals analysed as part of this project, nine are assigned male biological sex, with the remaining three individuals comprising a female and two of indeterminate biological sex (Appendix A Table A.4). The inclusion of this small sample in this study was considered due to its environmental context and in that it preserves an important record of the Copper Age on the Po Valley, which has traditionally defined the north Italian Copper Age. Preliminary analysis of the cross-sectional geometry of lower limb has demonstrated contrasting adaptations to terrain and mobility behaviours between the Forlì-Celletta and Ponte San Pietro assemblages (Parkinson *et al.*, 2018).

3.5 Central Italy

A composite sample of 36 articulated individuals ascribed to the Early Copper Age *Rinaldone* burial tradition was amassed from two sites from the Adriatic and Tyrrhenian coasts of central Italy.

3.5.1 Ponte San Pietro

The necropolis of Ponte San Pietro, Ischia di Castro, Latium (Figure 3.1, no. 9) dates to the Early Copper Age (3600-3000 cal. BC) (Table 3.2; Figure 3.2). Discovered in 1941, excavations by Luigi Cardini and Ferrante Rittatore throughout the 1940s and 1950s (Miari, 1993) uncovered a series of 25 rock-cut tombs of the *a forno* - or 'oven shaped' – type, consisting of an entrance shaft and chamber. The tombs contained either single, double and multiple burials, both disarticulated and articulated (Miari, 1994). The site is associated with the *Rinaldone* "culture" (see Chapter Two, Section 2.4.2) which spans the Tuscany, Lazio and Umbria regions and forms the centre of the *Gruppo di Ponte San Pietro*, a dense cluster of over 50 burial sites in Tyrrhenian central Italy (Cocchi Genick, 2009; Negroni Catacchio *et al.*, 2016). An important feature of the site is tomb 20, the so-called "Tomb of the Widow", which contained a central primary burial of an adult male associated with a rich funerary assemblage that included a classic *Rinaldone* style flask, copper dagger, polished stone axe, 15 arrow heads and a quiver made of red deer horn (Miari, 1994; Tagliacozzo and Fiore, 2011). The skeletal assemblage from Ponte San Pietro is exceptionally well preserved and in recent years was the subject of a programme of radiocarbon dating (Dolfini, 2010) that has helped to redefine the chronology of metallurgy in the central Mediterranean, as well as renewed osteological study (Negroni Catacchio *et al.*, 2014), as a part of a wider research programme into Copper Age groups in central Italy (Zavattaro *et al.*, 2012). The assemblage from Ponte San Pietro has also featured in region-wide studies investigating biological affinity in Italian Copper Age groups (Di Marco *et al.*, 2012; Varigu *et al.*, 2009) and is an important record for the bioarchaeology of Copper Age Italy. The assemblage from Ponte San Pietro consists of articulated and partially articulated burials and commingled deposits (Appendix A, Table A.1; Table A.5).

3.5.2 Fontenoce di Recanati (Area Guzzini)

Fontenoce di Recanati (otherwise referred to as Area Guzzini) is an Early Copper Age (3600-3300 cal. BC) necropolis of 21 rock-cut tombs south of Ancona, Marche (Figure 3.1, no. 8). As with Ponte San Pietro, the tombs are of the *a forno* type and exhibit similarities with other Copper Age sites west of the Apennines (Silvestrini and Pignocchi, 1997; Silvestrini *et al.*, 1993, 2011). The site is considered as an eastern extension of the *Rinaldone* burial tradition (Dolfini, 2010; Silvestrini *et al.*, 2004), although important differences between the Copper Age of Tyrrhenian and Adriatic central Italy have been discussed at length (see Cazzella and Moscoloni, 2012b; Chapter Two, Section 2.4.2). The tombs mostly contained single articulated inhumations, although some tombs (tombs 3, 12 and 14) contained multiple phases of burial activity and secondary depositions. Individuals were usually buried in a crouched position, although exceptions occur, such as individual 12.2 (Tomb 12) who was found supine with flexed legs. A high proportion of juvenile burials compared to other sites, alongside the remains of a dog (Tomb 6) and a partially articulated pig (Tomb 3) are notable peculiarities of the burial rites observed on site (Silvestrini *et al.*, 2011). Higher incidences of juvenile burials are typical for Copper Age sites in Adriatic central Italy, in comparison to those in Tyrrhenian central Italy, and males and females are similarly represented (Dolfini, 2006a, 2006b). Essential osteological analysis has been undertaken on the human remains from Fontenoce-Recanati (Silvestrini *et al.*, 2011), as well as preliminary palaeodietary analysis (Cianfanelli *et al.*, 2015; De Angelis *et al.*, 2019; Martinez-Labarga *et al.*, 2016) and comparative studies investigating biological affinity among Copper Age groups through cranial morphology (Di Marco *et al.*, 2012) and dental non-metric traits (Varigu *et al.*, 2009). The site has also been subject to an extensive programme of radiocarbon dating over the past decade (Cazzella and Silvestrini, 2005; Dolfini, 2010; Dolfini *et al.*, 2011) that has helped to redefine the chronology of Copper Age Italy. The 16 articulated individuals from Fontenoce-Recanati are listed in Appendix A in Table A.6.

3.6 Southern Italy

A small comparative sample of 15 Early-Middle Neolithic (ca. 6000-4500 cal. BC) individuals from southern Italy were included in the study in order to explore spatial variation between Neolithic Italian groups and temporal variation across the 6th-3rd millennia BC. Funerary practices in Early and Middle Neolithic southern Italy varied considerably (Robb, 1994, 2007; see Dolfini, 2015; see Chapter Two, Section 2.3); however, single inhumation burials within domestic contexts, often within ditches demarcating settlements, were largely the norm. It was necessary to construct a composite sample of 15 individuals from five sites from Apulia and Basilicata (see Appendix A, Table A.1; Table A.7).

3.6.1 Ripa Tetta

The Early Neolithic ditched village of Ripa Tetta, situated between Lucera and Foggia in Puglia (Figure 3.1, no.11), was excavated from 1982-1992 by the University of Pisa (Tozzi, 1985, 1988; Tozzi and Verola, 1991). Associated with the Early Neolithic *Ceramica Impressa*

(*Guadone*/*Lagnano da Piede* wares) ceramic style, the well preserved site constitutes an important record for the south Italian Early Neolithic (Tozzi, 2015). Excavations focused on the northern and southern extents of the settlement and uncovered a domestic structure, ovens and cobbled surfaces set within a circular ditched enclosure measuring ca. 100m in diameter (Tozzi, 2015; Tozzi and Verola, 1991) and a total of four burials (Robb, 1994; Tozzi, 2015). A double burial, containing the articulated remains of a male and the disturbed remains of a female, was uncovered within an internal ditch located towards the centre of the site (southwestern extent of Trench S, Area EL). Further poorly preserved human remains were uncovered elsewhere in the site, in the ditch at the northernmost extent of the site (Trench L) and to the east of the site (Trench F). The two individuals from the double burial are included in the analysis of body size.

3.6.2 Trasano

The site of Trasano, located in Matera, Basilicata (Figure 3.1, no. 13), was excavated in the 1980s (Guilaine and Cremonesi, 1987; Marracci *et al.*, 2012). The excavations revealed a Middle Neolithic village enclosed with a stone wall and a number of burials. The burials consisted of two primary inhumations within pits, one of which featured a trepanation (Mallegni and Valassina, 1996), associated with the *Ceramica Dipinta* pottery style, and two single primary burials and a multiple burial containing three individuals associated with the *Serra d'Alto* pottery style (Robb, 1994). Trasano stands as an important record of the Neolithic in southern Italy beyond the Tavoliere. However a lack of radiocarbon dating or systematic published analysis of the skeletal remains hampers the analysis. Five individuals from the *Ceramic Dipinta* and *Serra d'Alto* layers at Trasano are included in the analysis of cross-sectional geometry of the humerus and tibia (Appendix A Table A.7).

3.6.3 Samari

The site of Samari, Lecce (Figure 3.1, no. 14), consists of two cist burials each containing single primary burials of a male and female (Robb, 1994). Other deposits of commingled human remains were uncovered and the site is often cited as an example of the plurality of southern Italian Neolithic burial traditions (Dolfini, 2015; Robb, 2007). Unfortunately, the site has not been radiocarbon dated, but can be assigned a relative date to the Early Neolithic on the basis of associated *Ceramica Impressa* ceramics material. The two articulated individuals from the cists are included in the analysis of body size.

3.6.4 *Masseria Candelaro*

The site of Masseria Candelaro is located on the juncture between the Tavoliere and Gargano peninsula 14km SW of Manfredonia (Figure 3.1, no. 10). The site was excavated from the 1970s to the 1990s (Cassano and Manfredini, 1990; Manfredini and Cassano, 2005) and consists of an Early Neolithic settlement (early 6th millennium BC; Candelaro phase I), which was expanded in the Middle Neolithic during the mid-6th millennium BC (Candelaro phase II), and later reused for ritual and funerary purposes in the Middle-Late Neolithic in the later 6th millennium BC (Candelaro phase III) (Manfredini and Muntoni, 2005). The human remains of 23 individuals come from the *Ceramica Dipinta* and *Serra d'Alto* contexts (Candelaro phases II and III), spanning the middle and late 6th millennium BC (Figure 3.2; Table), and consist of both primary and secondary burials (Cassano and Manfredini, 1991; Robb, 1994; Salvadei *et al.*, 2005). The primary burials were found in pits within the extant village ditch, whilst eight skulls and scatters of loose bone were found piled together within a large non-domestic structure (Structure Q). Osteological analysis of the Masseria Candelaro human remains included pathological indicators of nutrition, and analysis of post-cranial and dental morphology (Salvadei *et al.*, 2005). Recent analysis of the strontium isotope values from the individuals from Masseria Candelaro demonstrated that the group was relatively homogenous and consistent with samples from contemporary Tavoliere settlements, in contrast to individuals from the nearby collective burial cave of Scaloria (Tafuri *et al.*, 2016). Of the 23 individuals from Masseria Candelaro, only four had sufficient enough preservation to be included in the study of cross-sectional geometry (Appendix A Table A.7).

3.6.5 *Fonteviva*

Masseria Fonteviva (Foggia) is a Neolithic settlement situated on the Apulian Tavoliere (Figure 3.1, no. 12) featuring a small rock-cut domed chamber at the base of the 'c'-shaped ditch (Trump, 1987). The tomb at Fonteviva is commonly cited as an early example of a rock-cut tomb (Guilaine, 2015; Whitehouse, 1972) and contained the remains of two adult female individuals aged 35-45 years and the fragmented remains of a juvenile. Field notes and sketches accompanying the material indicate that the first individual (42.5.6) lay in a crouched position, whilst the second individual (42.5.7) was lying face down with a flint blade beneath their pelvis. The two individuals were found at separate levels, with 25 cm of deposit between them, towards the back of the tomb. Establishing a date for the Fonteviva tomb was problematic due to insufficient recording by Bradford, who excavated the tomb in 1950, but died before publishing his results. Trump attributed the chamber to the Middle Neolithic on the basis of ceramic finds and interpretation of Bradford's note books, noting that the chamber appeared to have been cut into the ditch whilst it was still open (Trump, 1987), although a later date was considered. A programme of radiocarbon dating was undertaken on both adult individuals to establish an absolute date for the assemblage (Table 3.2) and confirmed the individuals to be Early-Middle Neolithic in date. Femora from the individuals were included in the analysis of body size (Appendix A, Table A.1).

3.7 European Comparative Dataset

The increasing availability of large open access datasets is one of the major advancements in archaeology in recent times that has facilitated the development of 'big data' approaches which have the potential to explore large scale spatio-temporal trends on a previously unimaginable scale (Cooper and Green, 2015). One such recent dataset is the Ruff (2018c) European Database, which contains skeletal dimensions, long bone cross-section and body size data for over 2,000 individuals from a cross ca. 25,000 years of European prehistory and history. Raw osteometric data from 224 articulated individuals (129 males, 95 females) (Table 3.3) from southern Europe spanning the Upper Palaeolithic to the Modern period were included in the analysis of body size and long bone cross-sectional geometry in order to explore long-term trends in the central Mediterranean.

Table 3.3: Sample composition and approximate date ranges for Ruff (2018c) data set time periods.

Upper Palaeolithic	ca. 25000-10000	17	12	29
Mesolithic	10000-6000	21	8	29
Bronze Age	1500-1000	17	17	34
Roman	1-250 AD	23	22	45
Medieval	750-1350 AD	29	25	54
Modern	1800-1900 AD	22	11	33

See Appendix A Table A.8 for full breakdown of sites.

The majority of the comparative dataset is composed of French and Italian skeletons analysed by Holt *et al*. (2018b), with two additional sites from Switzerland and Romania (Figure 3.3; Table 3.3). A full list of all comparative samples and their cultural attribution is provided in Table A.8 in Appendix A. Holt *et al*. (2018b) analysed temporal trends in long bone robusticity and body size in France and Italy, combining material from both these regions. Only Italian data were isolated for the Bronze Age, Roman, Medieval and Modern samples, but additional comparative data from adjacent areas (France, Alps and the Balkans) were added to the Upper Palaeolithic and Mesolithic samples so as to increase their sample size. Although Holt *et al.*'s (2018b) dataset for France and Italy does include Neolithic and Copper Age material, their Italian Neolithic sample only consists of nine of the 16 individuals from

Fontenoce-Recanati analysed as part of this study – and are actually Copper Age in date (see Section 3.5.2). Therefore, the data collected in the present study provides an extremely important supplement to the Ruff (2018c) European Database.

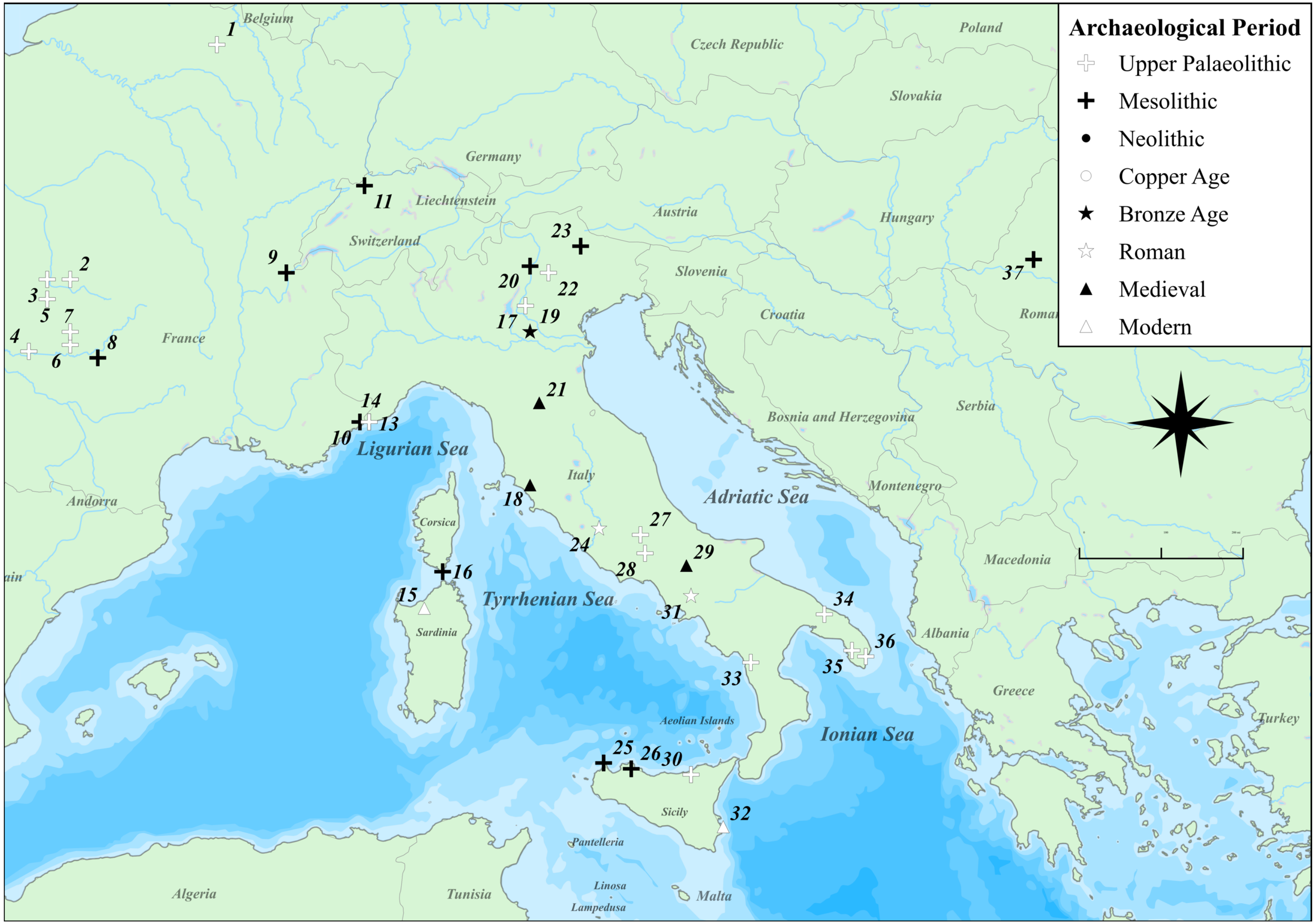


Figure 3.3 – Map displaying location of comparative material isolated from the Ruff (2018c) European dataset. Sites separated by time period and numbers correspond to Table A.8 in Appendix A. Date ranges for time periods are shown in Table 3.3.

3.8 Conclusion

The 17 assemblages analysed as part of this study provide a large representative sample for the central Mediterranean Neolithic and Copper Age and represent one of the largest comparative databases of bioarchaeological data collected for the region in recent times. The initial sampling strategy of this project aimed to ensure all time periods, archaeological contexts and geographical areas were represented. Whilst every attempt was made to achieve this, it was not possible to gain a full coverage of some geographical areas for both the Neolithic and Copper Age within the scope of this PhD project as a result of a lack of available material, fieldwork curtailment and curatorial constraints. Only in Sardinia and northern Italy was it possible to gather data on both the Neolithic and Copper Age. Furthermore, areas such as Sicily, where Neolithic and Copper Age skeletal material is rare and extremely challenging to trace (Becker, 1996; Leonini and Sarti, 2006), are completely absent in the present study, despite best efforts to include material from this sub-region. The samples collected as part of this study also form an important supplement to the Ruff (2018c) European Database, which lacks adequate data for the Neolithic and Copper Age of Italy, Sardinia and the Maltese Islands.

4 METHODOLOGICAL CHALLENGES IN THE STUDY OF COMMINGLED AND FRAGMENTARY HUMAN REMAINS

4.1 Introduction

This chapter introduces the methodological challenges and approaches used in the analysis of commingled human remains within this study. Commingling refers to the spatial intermixing of human remains from two or more individuals, usually to such an extent where it is difficult or impossible to re-associate skeletal elements to a single individual. Fragmentation is a further common consequence of the many and varied taphonomic processes that cause commingling. Such skeletal material, therefore, poses considerable methodological challenges, especially in studies that rely on the acquisition of osteometric data. The analysis of such material is made all the more challenging by how much the degree of commingling and fragmentation varies between assemblages, because of the case-specific nature of deposition, and the many combinations of cultural and natural taphonomic processes that can occur (Figure 4.1). Many of the commingled assemblages analysed in this study can be defined as long-term use assemblages (Osterholtz *et al.*, 2014b), characterised by higher instances of fragmentation and disarticulation resulting from periodic reworking of the human remains over several centuries. In some cases, assemblages appear to have undergone further post-excavation commingling in their respective curatorial settings. Despite the considerable challenges posed by commingled skeletal assemblages, the application of 3D surface scanning technology in this study has aided in the estimation of bone dimensions that are necessary for the acquisition of cross-sectional geometric (henceforth CSG) properties through the method developed by Davies *et al.* (2012).

Few studies have attempted to analyse long bone CSG properties in commingled and fragmentary skeletal material owing to the difficulties of acquiring the necessary osteometric data. Stock and Willmore (2003) investigated broad patterns of habitual activity through the application of skeletal biomechanics in a large fragmented and commingled Iroquoian burial assemblage, successfully illustrating the validity of such studies. Similarly, palaeoanthropological studies have demonstrated the wealth of information that can be extracted from fragmented skeletal material and small sample sizes (Ruff, 2008b; Trinkaus and Ruff, 1999; Xing *et al.*, 2018), providing a strong methodological framework on which to build. In particular, the analysis of a large commingled and fragmented assemblage of *Homo naledi* remains (see Marchi *et al.*, 2017) has effectively addressed many of the issues faced in this research.

Long term use assemblages
Active over long term (i.e. communal tomb)

- Periodic reworking of human remains – both intentional and unintentional
- Greater fragmentation and commingling
- Demographic profile reflective of cultural practices

→

- **Primary burial**
  Deposition of new burials alongside older burials. New burials decompose naturally, some movement of skeletal elements (i.e. smaller elements fall to bottom)
- **Secondary burial**
  Deposition of human remains which decomposed elsewhere (possible processing i.e burning, defleshing)
  Smaller/residual elements tend to be underrepresented following process of relocation

Episodic/short term use assemblages
Active over short time (i.e mass disaster or genocide)

- Less commingling and fragmentation (varies by nature of event)
- Less/no processing of bodies
- Demographic profile reflects nature of event

→

- **Plague**
  Catastrophic mortality profile, all elements present, discrete primary burials
- **Warfare**
  Catastrophic mortality profile (possible young male bias), all elements present (exc. possible trophy taking), trauma
- **Genocide**
  Variable mortality profile, all elements likely present, trauma
- **Mass disaster**
  Flat demographic profile (all ages, sexes). Variable element representation and fragmentation
- **Vertebrate interaction**
  Animal scavenging and burrowing into burial environment

Lab commingling
Accidental commingling of human remains in curatorial setting

- Variable levels of commingling/fragmentation

→

- **Conflict/natural disaster** – Museums collections moved quickly or destroyed (i.e. war or natural disasters)
- **Removal of context –** Loss or destruction of identifying labels/containers/bags

Figure 4.1 – Modes of commingling modified from Osterholtz et al. (2014b).

The core osteometric data that is necessary for analysis of CSG properties are maximum bone length and femoral head diameter (see Chapter Six, Section 6.3). Maximum bone length is not only required to accurately determine standardised cross-section locations along the 'mechanical' length of the diaphysis (the portion of the diaphysis that spans 20-80% of maximum length), such as the femoral and tibial mid-shaft (50% of bone length) and mid-distal humerus (35% of bone length) (Ruff and Hayes, 1983a; Figure 4.2), but bone length is also a vital component in the standardisation of CSG properties for the mechanical influence of body size (Ruff, 2002, 2008, 2019; Ruff *et al.*, 1993). Unlike other methods, the automated program AsciiSection used in this study (see Davies *et al.*, 2012) requires maximum length to calculate cross-section locations and properties. Similarly, femoral head diameter is a metric that is essential for body mass estimations, which are also central to standardising CSG properties for the influence of body size. Applying the CSG method to the prehistoric assemblages used in this study therefore required accurate estimates of complete bone length and femoral head diameter from isolated and fragmentary long bones, which was made possible through the application of 3D surface scanning.

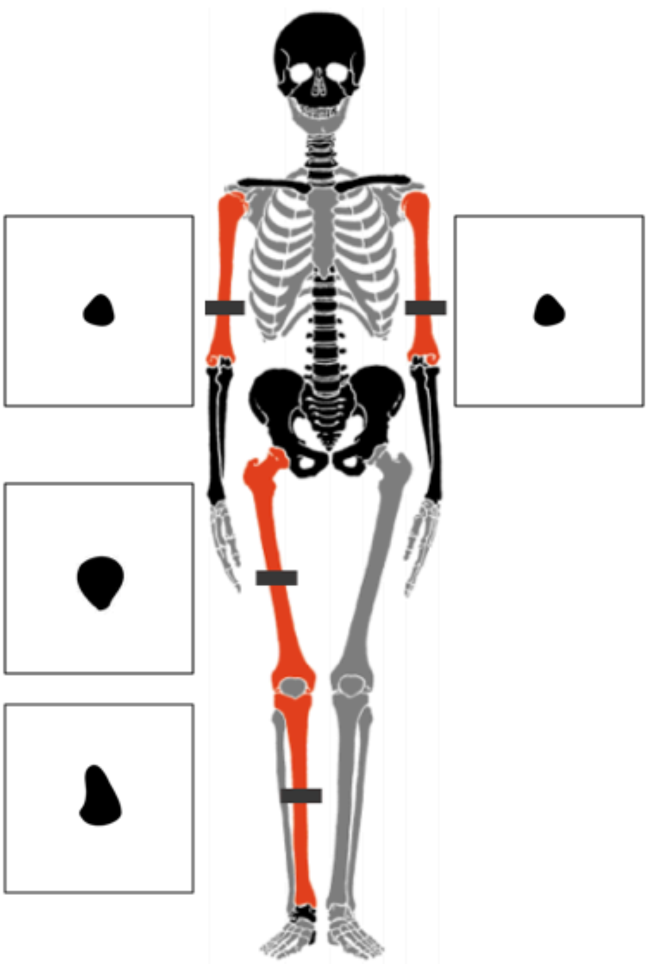


Figure 4.2 – Standard long bone cross-section locations used in this study (after Ruff 2018).

Table 4.1: Summary of assemblage preservation (see Chapter Three for full contextual details of individual sites).

No.	Site	Sample preservation	Fragmentation summary
1	Saint-Martin-de-Corléans	Long term use assemblage	Fragmentation
2	Arene Candide	Primary burials	Limited fragmentation
3	Arma dell'Aquila	Primary burials, episodic commingling*	Limited fragmentation
4	Grotta Pollera	Primary burials	Limited fragmentation
5	Bergeggi	Primary burials	Limited fragmentation
6	Pian del Ciliegio	Primary burials	Limited fragmentation
7	Forlì-Celletta	Primary burials	Very fragmentary, excavation damage
8	Fontenoce-Recanati	Primary burials	Limited fragmentation
9	Ponte San Pietro	Primary burials	Limited fragmentation
10	Masseria Candelaro	Primary burials	Fragmentation
11	Fonteviva	Primary burials	Considerable fragmentation
12	Ripa Tetta	Primary burials	Limited fragmentation
13	Trasano	Primary burials	Limited fragmentation
14	Samari	Primary burials	Considerable fragmentation
15	San Benedetto-Iglesias	Long term use assemblage, lab commingling(?)	Limited fragmentation
16	Sacaba'e Arriu	Long term use assemblage	Fragmentation
17	Xagħra hypogeum	Long term use assemblage, lab commingling	Considerable fragmentation

*Sparacello *et al*. (2019) note that commingling/disturbance occurred at Arma dell'Aquila as a result of cave collapse and deposit slippage.

The challenges of working with commingled and fragmented human remains are referenced and discussed throughout this thesis, and specific issues that are particular to certain types of analysis are discussed in their relevant chapters (for body size see Chapter Five, for skeletal biomechanics see Chapters Six and Seven). However, it is also necessary to introduce some of the more general issues and specific methodologies that were adopted. The following section provides a short introduction to the core practical and methodological considerations that were taken into account, followed by overviews of individual methodologies that were employed.

4.2 Commingling: practical and methodological considerations

Approaches to the study of commingled human remains have greatly advanced in recent years, as highlighted by a number of recent volumes dedicated to developing methodology (Adams and Byrd, 2008, 2014; Osterholtz, 2016; Osterholtz *et al.*, 2014a) and showcasing archaeological case studies (Schmitt *et al.*, 2018; Tomé *et al.*, 2016). In spite of these recent developments, there still remains a negative research bias against assemblages of commingled human remains. The highly variable and case specific nature of commingling, which stems from the multitude of taphonomic processes that can be involved, means that each individual assemblage requires a carefully considered and tailored approach (Ubelaker, 2008). Table 4.1 lists the primary assemblages analysed as part of this study and summarises their state of preservation and the mode of commingling, in accordance with those defined by Osterholtz *et al*. (2014b; Figure 4.1)

The study of human remains varies globally, and even between the United Kingdom (White, 2011), Malta (Pace, 2011) and Italy (Piombino-Mascali and Zink, 2011): regional academic traditions, alongside regional differences in the archaeological record, have strongly dictated the field of bioarchaeological research and the study of commingled bone. Within the United Kingdom, official *Historic England* guidelines state that disarticulated human remains are of “limited scientific value” and “not usually considered worthy of study” (Mays *et al.*, 2004). This sentiment has unfortunately been echoed more recently (Mays, 2017), although the intended commercial application of such guidelines should be acknowledged. In commercial investigations with time pressure and limited resources, the time-consuming analysis of complex commingled assemblages is simply not always feasible. It is important to emphasise, however, that by not adequately analysing commingled assemblages bioarchaeologists run the risk of overlooking entire geographical areas or time periods, and cultural contexts within them, where communal burial practices are the norm. Within the central Mediterranean, funerary sites often consist of a mixture of articulated and disarticulated individuals (as at Ponte San Pietro, see Chapter 3, Section 3.5.1), with certain individuals purposefully kept intact by members of their community for cultural reasons (Dolfini, 2006a). Consequently, by only analysing articulated and well-preserved human remains from an archaeological site, bioarchaeologists overlook these important social and cultural factors, and risk restricting their analysis to a sub-set of buried individuals who are not fully representative of the entire burial community.

In Malta and Italy, however, fragmented human remains are encountered far more regularly and therefore are incorporated more widely into bioarchaeological research. Guidance from the *British Association for Biological Anthropology and Osteoarchaeology* (Mitchell and Brickley, 2017) offers a more optimistic view that highlights the role of archaeological science and biomolecular archaeology in enabling highly efficient and targeted analysis of selected skeletal elements (i.e. isolation of dentition from commingled assemblages for stable isotope analysis). In general, the aversion towards studying commingled human remains stems from 1) the generalised nature of the research outcomes, 2) the increased potential for lower sample sizes and 3) the practical difficulties of analysing such skeletal material.

At the outset, the information that can be extracted from commingled assemblages is indeed more limited when compared to analysis of articulated individuals - a fact which many practitioners identify as a problem. However, by driving bioarchaeologists towards broad conclusions at the population level, rather than unique and isolated case studies of discrete individuals, research on commingled samples has the potential to have greater and more meaningful impact on the wider archaeological community. Commingled assemblages also offer archaeologists an opportunity to take a truly randomised approach to sampling a population, although admittedly this is less true in cases where cultural processes and selective inclusion may dictate the demographic parameters of a burial assemblage (as is the case with Saint-Martin-de-Corléans, see Chapter Three, Section 3.4.2). Analysis of post-depositional processes and taphonomy also provides powerful insights into funerary practices (Robb *et al.*, 2015).

Extreme fragmentation as a result of commingling can also limit the availability of intact skeletal elements and lead to low samples sizes - an issue that bioarchaeologists have become increasingly preoccupied with (Jackes, 2011). It is important to emphasise however, that as archaeologists, we are all constrained by the material available. Many of the assemblages analysed here are unique in that they are the only surviving skeletal material for their respective geographical areas or cultural contexts, and therefore their study is absolutely necessary and relevant. In a response to criticisms over sample size, Richards and Schulting (2006) argued that in terms of probability, lower numbers, in representing such a small sub-sample of a population, were less likely to pick out unusual or unrepresentative cases, and therefore were actually more likely to reflect the norm for the geographic areas and time periods under study.

In general, commingled material requires baseline analysis that establishes the Minimum Number of Individuals (MNI) and the demographic parameters of the assemblage (Rost, 1997). It was not within the scope of this study to examine all assemblages for baseline data although most sites have already undergone basic osteological analysis (see Chapter Three for overview of research materials). However, as this study involves focused analysis of particular skeletal elements (humerus, femur and tibia) selected from skeletally mature adults (i.e. elements with complete epiphyseal fusion), there was less need to acquire such information, as each sample consists of whatever skeletal material was available from across all adult age categories. Biological sex is an element of demography that is difficult to adequately assess in commingled assemblages, especially so in targeted studies that are restricted to a sub-set of particular skeletal elements. Numerous studies have attempted to use long bone dimensions to determine biological sex (González-Reimers *et al.*, 2000; Holman and Bennett, 1991; Kranioti and Apostol, 2015; Krüger *et al.*, 2017; Mall *et al.*, 2001; Safont *et al.*, 2000; Tomczyk *et al.*, 2017; Wrobel *et al.*, 2002). This approach relies on sexual dimorphism in body size and discriminant function analysis of epiphyseal and diaphyseal dimensions, whereby larger bones are designated as likely male and smaller bones as likely female. These approaches have indeed been shown to provide accurate sex determinations, although methods are population specific and are problematic when fragmentation is taken into consideration as acquiring comparable bone dimensions between long bones of variable preservation is not always possible. In this study, a preliminary exploration of using long bone length as a means of sex determination was undertaken to assess the potential of this approach. However, this resulted in considerably smaller samples sizes. For example, in the case of the assemblage of San Benedetto-Iglesias, attempts to determine sex on the basis of long bone length saw that of the 15 available tibiae, only 6 elements could be designated as likely male or female. Another drawback is that the accuracy of sex determination methods based on metric traits is much reduced when only one dimension is used (Mall *et al.*, 2001). Given the limitations, it was decided not to proceed with attempts to estimate the sex of individual long bones, and instead to treat the commingled assemblages as pooled sex samples during analysis.

4.3 Technical methods employed in this study

A series of adapted and original approaches were used to acquire accurate estimations of long bone length and femoral head diameter necessary for the standardisation of long bone CSG properties. The biomechanical analysis of long bones presented in Chapters Six and Seven relies on a method devised by Davies *et al*. (2012) that acquires solid diaphyseal cross-sections from 3D surface models of individual skeletal elements (see Chapter Six, Section 6.3.1 for specific details on the scanning methodology and long bone cross-sectional geometry). The use of 3D scanning to acquire long bone CSG properties therefore presented a further opportunity to use digital reconstruction in overcoming the methodological challenges of working fragmented skeletal material.

Ruff (2008a, 2019) recommends the use of estimated bone lengths when working with fragmented and isolated skeletal elements, and estimated bone lengths are widely used in the analysis of fragmentary fossil hominin material (Day and Molleson, 1976; Haeusler and McHenry, 2004; Korey, 1990; Ruff, 2008b; Trinkaus and Ruff, 1989, 1996; Trinkaus *et al.*, 1998). Slight misplacement of cross-section location within 5% of bone length has been shown to have little effect on CSG properties of the femur and humerus (Ruff, 2008b; Sládek *et al.*, 2010). Conversely, CSG properties of the tibia have been shown to be most sensitive to cross-section misplacement due to the irregular and angular morphology of the tibial medial and lateral surfaces (Sládek *et al.*, 2010). For this reason, extra care was taken to screen CSG data from tibiae, and only elements that were more than ca. 75% complete were selected for analysis.

4.3.1 Estimation of maximum bone length: 3D reconstruction and superimposition

Estimation of maximum bone length was achieved primarily through 3D digital reconstruction and 3D superimposition. Forensic anthropologists have developed a range of methods to estimate complete maximum bone length from fragmented long bones for the purposes of stature estimation (Jacobs, 1992; Simmons *et al.*, 1990; Steele, 1970; Steele and McKern, 1969; Wright and Vasquez, 2003), but available methods are problematic in that they are often exclusively developed for the lower limb and often calculate stature directly rather than provide an estimate of bone length. Considerable doubt has also been placed over the accuracy and repeatability of current methods for estimating complete length from fragmented long bones, which are population specific and often rely on highly variable anatomical landmarks (Bidmos, 2009) (see Chapter Five, Section 5.2.3 for full discussion).

A major benefit of a 3D scanning approach, however, is the opportunity to digitally manipulate skeletal elements in virtual space, enabling the use of techniques in 3D digital reconstruction and 3D superimposition (Figure 4.3). Both 3D digital reconstruction and 3D superimposition provide accurate estimates of complete long bone length, and have advantages over traditional visual approaches (Sylvester *et al.*, 2008). Long bone reconstruction was performed in Rapidform XOR using the Interactive Alignment function, where individual fragments were aligned and positioned according to anatomical landmarks, estimated anatomical axes and fracture congruence (Benazzi *et al.*, 2014; Grine *et al.*, 2010; Gunz *et al.*, 2009; Senck *et al.*, 2015). Once reconstructed, the individual fragment meshes were fused to form a single mesh using the Combine tool (Figure 4.3b). As with any analysis involving fragmentary skeletal material, digital reconstruction relies on careful documentation during the initial data collection stage and reference to, whenever possible, excavation notes. 3D digital reconstruction also offsets the need to undertake restoration and reconstruction of the physical skeletal element, which often requires the use of adhesives that can lead to serious long-term conservation issues (Caffell *et al.*, 2001; Johnson, 1994).

3D digital superimposition was undertaken to estimate complete bone length for incomplete fragmented skeletal elements, such as those without epiphyses. Similar to visual pair matching which is used widely in forensic (Adams and Byrd, 2006; Adams and Konigsberg, 2004) and palaeoanthropological (Marchi *et al.*, 2017; Trinkaus *et al.*, 1998) research, this approach compares the diaphyseal contours and anatomical landmarks of a fragmented skeletal element with a complete element from a reference collection. The combination of the incomplete and complete elements can then be used to make a reliable estimation of complete bone length (Figure 4.3a). Traditional visual comparison methods are more subjective, in that they rely on comparison between two bones positioned next to one-another, whilst 3D digital superimposition allows for clearer and more accurate comparisons to be made *in silico*, thus limiting subjectivity. In a test of this approach, Karell *et al*. (2016) showed that manual 3D superimposition outperformed automated matches and traditional visual comparison methods in 100% of comparisons. The application of 3D digital superimposition has also been effectively employed in analysis of very fragmented fossil hominin material (Xing *et al.*, 2018). 3D superimposition was performed in Rapidform XOR by importing a 3D mesh of a complete bone of similar size and morphology, on the basis of approximate length estimations made in the field. Incomplete bones were then positioned and orientated over the complete reference bone on the basis of comparable morphology, using the Interactive Alignment and Datum Match functions in Rapidform XOR. Whilst this approach requires experience in handling 3D data, as well as access to specialist software and 3D scanning equipment, 3D superimposition achieves reliable estimations of complete bone length (Figure 4.3a). In the case of fragmentary elements belonging to articulated individuals (i.e. two humeri from the same individual, the left missing a distal epiphysis and the right missing a proximal epiphysis), both sides were scanned and used to create ‘hypothetical’ reconstructions whereby the individual models where mirrored and superimposed on to the corresponding skeletal element.

Figure 4.3 – Examples of reconstructed humeri; A) 3D superimposed humerus, B) 3D digitally reconstructed humerus.

4.3.2 Estimating femoral head diameter: shape fitting

Femoral head diameter, required for the estimation of body mass (i.e. Ruff *et al.*, 1997), is also an important metric for the standardisation of CSG properties. Whilst the femur is one of the best surviving elements in archaeological contexts (Stojanowski *et al.*, 2002; Waldron, 1987), long bone epiphyses are often damaged in commingled assemblages (Adams and Byrd, 2006). In these cases, shape fitting can be used to estimate the diameter of fragmented femoral heads. By modelling the femoral head as a sphere and extrapolating the curvature of the surviving surface with the Measure Radius tool in Rapidform XOR, it was possible to estimate the complete diameter (Figure 4.4). The estimated radius was then multiplied by two to achieve an estimated femoral head diameter. Whilst this approach does assume sphericity of the femoral head, clinical and experimental research has shown that the femoral head can be confidently modelled as a sphere (Cereatti *et al.*, 2010; Hammond and Charnley, 1967; Kim, 1989) or partial sphere (Parkinson, 2014; Ruff, 1990, 2002; Rafferty and Ruff, 1994). Similar approaches applied to fossil hominin acetabula have proved an effective means of estimating femoral head size in palaeoanthropological literature (Berger *et al.*, 2010; Hammond *et al.*, 2013; MacLatchy and Bossert, 1996; Plavcan *et al.*, 2014a, 2014b).

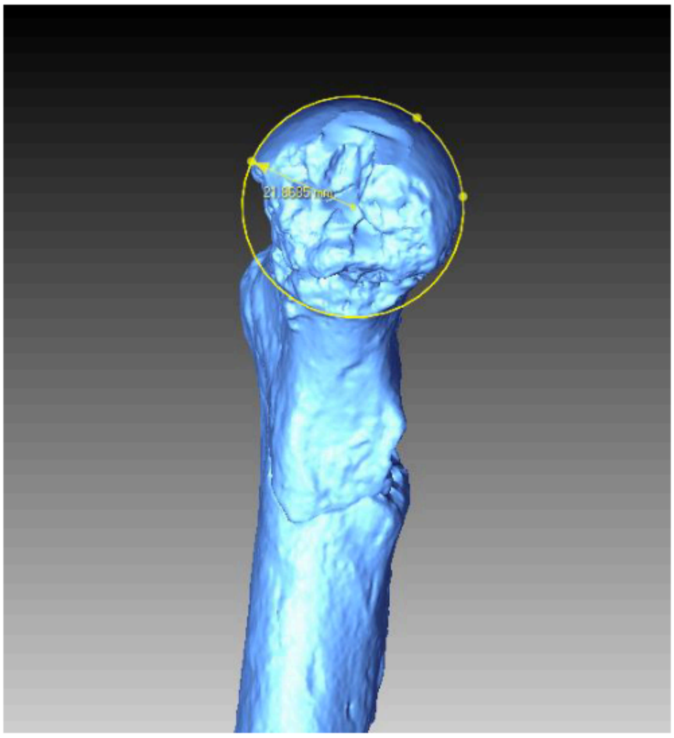


Figure 4.4 – Example of shape fitting method applied to fragmented femoral head. The femoral head is modelled as a sphere and the curvature of the surviving surface is then extrapolated to achieve an estimated diameter.

4.3.3 Resolution of small-scale commingling

In two cases it was also necessary to resolve small-scale commingling, stemming from post-excavation lab commingling or secondary burial. In the first case, the burial deposits at Samari appeared to have undergone further commingling in their curatorial environment, with duplicate skeletal elements found among the primary burial assemblages. In the second case, the container for individual no. 6416 from Ponte San Pietro contained a third humerus, presumably associated with a nearby secondary deposition or as a result of lab commingling. Standard methods in forensic archaeology, that consist of comparing of taphonomy (colouration), size, morphology and joint congruency (Adams and Byrd, 2006, 2008; Byrd and Adams, 2003), were used to identify the most likely corresponding elements and confidently exclude duplicate elements.

4.4 Conclusion

Acquisition of reliable and accurate osteometric data is a fundamental challenge of working with fragmentary and commingled human remains. This chapter has provided an overview of the technical methods that were employed in order to estimate maximum bone length and femoral head diameter. Many other methodological challenges were encountered throughout the analysis and interpretation of the data. Further methodology sections relating to specific aspects of analysis are provided in later chapters (Overview of body mass and stature estimation methods in Chapter Five, Section 5.2; Background on skeletal biomechanics and long bone cross-sectional geometry in Chapter Six, Section 6.3) and whenever necessary address further practical limitations in working with disarticulated human remains. For example, a critical review of methods for estimating stature from fragmentary long bones, which although touched upon in this chapter, was considered to be better suited to a wider discussion on stature and body mass estimation methods provided in Chapter Five.

This chapter has also discussed the challenges of analysing commingled human remains and addressed some of the wider issues related to commingling. The discussions in this chapter highlight the impact that recent developments in archaeological science have had on the study of complex commingled assemblages, enabling minimal and efficient sampling procedures that provide maximum results. Within the context of this study, the application of 3D laser scanning aided in the acquisition of osteometric data that would have otherwise been impossible and enabled a flexible approach whereby study materials could be revisited *in silico*, allowing methodologies to be constantly refined, developed and reapplied.

5 BODY SIZE AND NUTRITIONAL STATUS: SPATIAL AND TEMPORAL ANALYSIS OF STATURE AND BODY MASS

5.1 Introduction

Estimations of stature and body mass are fundamental components of osteological research, and therefore both have a long history of study in biological anthropology (White *et al.*, 2011). Emphasis has traditionally been placed on stature estimation in archaeological populations, whilst estimation of body mass is more pertinent in palaeoanthropological studies (Ruff and Niskanen, 2018; Ruff *et al.*, 1997, 2018; Squyres and Ruff, 2015; Will and Stock, 2015). Whereas body mass is characterised by a high degree of plasticity, in that it varies throughout life and is more responsive to nutritional status, adult stature has commonly been suggested to be under stronger genetic control, with some studies reporting stature heritability at 80-90% (Silventoinen *et al.*, 2003). However, final adult stature has been shown to be affected by non-genetic factors related to life history, growth impairment and the environment in which an individual develops, with the heritability of body size traits having likely been overemphasised (for review see Wells and Stock, 2011). In particular, growth impairment stemming from childhood malnutrition is an important factor that can influence final adult stature and overall adult health (Jee *et al.*, 2014; de Onis and Branca, 2016; Victora *et al.*, 2008). Body size is therefore an important means of exploring physiological stress and changes in nutritional status in response to differing socio-economic circumstances in archaeological contexts.

The relationship between body size and nutritional status has long been used by archaeologists and economic historians to investigate largescale temporal and spatial trends in socio-economic status in modern (Bielicki *et al.*, 1981; Castro-Porras *et al.*, 2018; Silventoinen *et al.*, 1999; Stock and Migliano, 2009; Tyrrell *et al.*, 2016) and archaeological (Formicola and Holt, 2007; Goldewijk and Jacobs, 2013; Macintosh *et al.*, 2016; Niskanen *et al.*, 2018; Piontek and Vancata, 2012; Stock *et al.*, 2011) populations. A particular emphasis has been placed on the negative health impacts of the transition to agriculture in Europe and North America (Cohen and Armelagos, 1984; Pinhasi and Stock, 2011), where a decrease in body size (Ehler and Vančata, 2009; Macintosh *et al.*, 2016; Mummert *et al.*, 2011; Piontek and Vancata, 2012) and increase in skeletal stress markers (Formicola, 1987; Larsen, 2015; Latham, 2013; Robson, 2010), have been associated with a decrease in overall population health. However, the relationship between genetic and non-genetic factors influencing body size (in particular stature) has also recently emerged in studies pertaining to European prehistory, and therefore should be addressed here.

On considering the potential influence of population history on body size, Martiniano *et al*. (2017) revealed that changes in genomic estimates of height corresponded with periods of cultural transition and population mobility in Iberian prehistory, suggesting the presence of a genetic component behind temporal trends in stature. More recently, Cox *et al.* (2019) explored the genetic contribution to final adult height by comparing long term trends in predicted genetic height with stature estimations derived from archaeological skeletons. Cox *et al.*'s (2019) study found that genetically determined height accurately predicted changes observed in stature data derived from archaeological skeletons in pre-agricultural groups, but suggested that discrepancies between the two forms of evidence following the transition to agriculture reflected points in time when environmental conditions influenced body size. The results of their study has major implications, in that it demonstrates how genetically predicted height can be used as a baseline to better understand long term body size trends that are related to environmental conditions.

Within the context of the present study, the degree to which the individual Neolithic and Copper Age groups are genetically associated is difficult to establish in the absence of ancient DNA studies in the central Mediterranean. Italian Copper Age groups were historically considered to be warrior pastoralists that migrated from the east and introduced metal technology (Puglisi, 1959; Trump, 1966), but this diffusionist narrative has since been heavily criticised (see Barker, 1981). Studies investigating biological affinity between central Mediterranean Neolithic and Copper Age populations, including some of the samples presented in this analysis, have been undertaken using cranial morphology (Di Marco *et al.*, 2011, 2012) and suggest that Copper Age groups in northern Italy may have been genetically distinct from the preceding Neolithic population, whilst identifying homogeneity between central Italian Copper Age and Neolithic populations.

For Malta, ongoing ancient DNA analysis of human remains from the Brochtorff-Xagħra Circle has indicated that the Late Neolithic population of Malta held genetic affinity with European Early LBK Neolithic populations up to, and throughout, the 3rd millennium BC (pers. comm., Bradley, D. 2018), whilst in Sardinia, the island's population is traditionally characterised by genetic continuity from the Neolithic onwards (D'Amore *et al.*, 2010a; Olivieri *et al.*, 2017). On the basis of the available evidence, the population history of the central Mediterranean seems to differ from established patterns of population mobility for wider Europe, which saw largescale genomic transformation in the mid-3rd millennium BC (Goldberg *et al.*, 2017; Lazaridis and Reich, 2017; Olalde *et al.*, 2018). The homogeneity of the central Mediterranean population throughout the Neolithic and Copper Age therefore suggest that there is limited potential for population history to have had an influence over spatial and temporal trends in body size during these two periods.

Consideration of body proportions, such as limb segment lengths or crural/brachial indices, in combination with body size variables, is an approach that has been adopted elsewhere (Macintosh *et al.*, 2016; Walter, 2017). Body proportions have also been suggested to be under stronger genetic control (Cowgill *et al.*, 2012; Livshits *et al.*, 2002), but these too have been shown to vary according to climate (Allen, 1877; Buck *et al.*, 2018; Serrat *et al.*, 2008) and environmental stress (Payne *et al.*, 2018; Pomeroy *et al.*, 2012). However, analysis of limb segment length was not possible in the context of this study, given that most of the skeletal assemblages are characterised by high levels of commingling and fragmentation (see Chapter Three), although an analysis of asymmetry in humeral length is included in Chapter Six. In acknowledgement of the fragmentary and commingled nature of the skeletal assemblages analysed in this study, this chapter also includes a critical review of the various methods that are available for estimating stature and body mass in archaeological populations.

5.1.1 Body size in central Mediterranean prehistory

Previous studies have investigated body size in the central Mediterranean at both regional (Holt *et al.*, 2018; Martella *et al.*, 2016) and sub-regional (Barbieri *et al.*, 2017;Corrain, 1982, 1986; Floris *et al.*, 2012; Giannecchini and Moggi-Cecchi, 2008; Marongiu *et al.*, 2011) scales, or drawn the central Mediterranean into broader European comparisons (Danubio *et al.*, 2017; Formicola and Holt, 2007; Niskanen *et al.*, 2018; Ruff *et al.*, 2006a), interpreting the results within an economic framework. However, comprehensive regional syntheses of stature and body mass are significantly hampered by the difficulties of comparing published body mass and stature estimations for archaeological populations that have been derived using different methods (Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016). In recognition of this issue, Martella *et al.* (2016) called for more data sharing, collaboration and publication of raw osteometric data that would enable such regional syntheses. In Ruff's (2018c) recent review of skeletal robusticity and body size across ca. 24,000 years of prehistory and history, Niskanen *et al.* (2018) and Holt *et al*. (2018a) examined trends in body size across Europe, France and Italy, producing a database of raw osteometric data for over 2,000 individuals, and in doing so creating a solid foundation for further detailed regional analysis (see Chapter Three, Section 3.7). Holt *et al.*'s (2018b) combined study of France and Italy contains a comprehensive record for pre-agricultural and post-Bronze Age collections, although a lack of Neolithic and Copper Age samples unfortunately conceals the potential of exploring changes in body size during these times of crucial change (see Chapter Three, Section 3.8). Therefore, the primary data collected as part of this study form of a vital comparative sample that complements the pre-existing published data.

In general, most previous studies show a decrease in stature and body mass in the central Mediterranean Neolithic relative to later time periods (Barbieri *et al.*, 2017; Danubio *et al.*, 2017; Floris *et al.*, 2012; Holt *et al.*, 2018b; Martella *et al.*, 2016; Sparacello, 2013), and a decline in body size during the Roman period (Floris *et al.*, 2012; Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016). This trend mirrors that of wider prehistoric Europe (Ehler and Vančata, 2009; Piontek and Vancata, 2012; Macintosh *et al.*, 2016; Niskanen *et al.*, 2018), North Africa (Stock *et al.*, 2011) and North America (Larsen, 2015; Mummert *et al.*, 2011). However, body size after the Neolithic, particularly during the Copper Age, has yet to be comprehensively investigated, despite its potential to lend insights into economic and social change at this time.

Macintosh *et al*. (2016) showed that the decline in overall body size with the onset of agriculture in south-central Europe was accompanied by a divergence between males and females, but that this sexual dimorphism then decreased in the Metal Ages. Their results showed that Early Neolithic females had considerably smaller body size than males, which was interpreted as reflecting social inequality between the sexes that negatively impacted on nutritional status among women. The results from Macintosh *et al.* (2016) were supported by pre-existing pathological and dietary studies, and thus emphasise the validity of diachronic studies and social interpretations of bioarchaeological body size data in prehistory.

Accurate chronology is also an important component of any investigation of spatial and temporal trends. In a focused study on Sardinian stature from the Neolithic to the Medieval period, Floris *et al.* (2012) documented decreased stature among Sardinian Neolithic and Copper Age groups, followed by an improvement in the Bronze Age, and a second decline in the Roman period. However, Floris *et al.'s* (2012) study relied on skeletal assemblages with poorly defined chronology, and extensive radiocarbon dating has since shown that some skeletal material included in their analysis was incorrectly dated. In particular, the human remains from Is Aruttas-Cabras, ascribed to the Late Neolithic group, and having long been considered to date to the *Ozieri I* phase (Germanà, 1995), have been shown to date to the Bronze Age *Nuragic* period (Lai, 2008), and therefore the results presented by Floris *et al.* (2012) cannot be considered accurate. More recently, however, a similar long-term trend has been reported for Sardinia and adjacent areas from the Neolithic to the Medieval period (Danubio *et al.*, 2017; Martella *et al.*, 2016). In acknowledgement of this potential issue, the skeletal materials discussed and analysed in this chapter have a secure chronology and archaeological context (see Chapter Three).

5.1.2 Research question one

Body size can therefore be used as a proxy for nutritional status in archaeological groups and has the potential to shed light on how the social and economic processes associated with the 4^{th}-3^{rd} millennia BC in the central Mediterranean impacted on the human body. Some expected outcomes of the analysis can be proposed on the basis of previous research in the central Mediterranean and wider Europe. 1) It is expected that there will be a reduction in body size during the Neolithic, reflecting the initial negative impact of agricultural subsistence on human health. 2) Body size is expected to gradually recover after the Neolithic as agricultural practices diversified and as consumption of secondary productions (i.e. dairy) increased (Robb, 1994b). 3) The important social, political and economic changes during the Roman period might also be expected to prompt a marked change in body size. 4) Marked sexual dimorphism in body size might occur during the Neolithic and decline in the Metal Ages, as documented in central-southern Europe (Macintosh *et al*., 2016). Conversely sexual dimorphism in body size might occur in the metal age, reflecting the formation of a binary gender ideology closely to biological sex (Robb, 1994a; Whitehouse, 2001). This chapter will explore these hypotheses in order to address the following research question outlined in Chapter One:

> *Research Question 1) Do body size and nutritional status change in response to economic and social change during the 4th-3rd millennia BC?*

5.2 Stature estimation methods

A range of methods have been developed to estimate stature in archaeological populations, although the applicability of individual techniques to the commingled and fragmentary assemblages analysed in this study must be considered. Whilst direct measurement of a skeleton in a grave is the most direct means of estimating living stature (Mays, 2010; Petersen, 2005), this approach is only applicable to articulated supine burials which are rare in prehistoric contexts, and in general most methods rely on stature estimations derived from osteometric data.

Stature estimation techniques are commonly based on the prediction of living stature through either an *anatomical* approach, which uses combined dimension of numerous skeletal elements, or a *mathematical* approach, which uses regression formulae developed on skeletal elements strongly correlated with living stature. Both mathematical and anatomical approaches have their specific limitations, either related to issues of bone preservation or in that they do not fully account for variation in body proportions. Other approaches have attempted to consider body size more broadly by analysing raw bone lengths (Goldewijk and Jacobs, 2013;

Mieklejohn and Babb, 2011; Piontek and Vancata, 2012). Although analysis of raw bone length has useful heuristic value and overcomes the error associated with using formulae (Mieklejohn and Babb, 2011), this approach still fails to fully account for the fundamental issue related to differing body proportions within groups (see Section 5.1.3).

5.2.1 Anatomical methods

The anatomical method relies on the measurement of the individual skeletal elements combined with an estimation of the soft tissue structures that contribute to stature. First developed by Fully (1956), and subsequently revised by Raxter *et al.* (2006, 2007), the anatomical method adequately accounts for differences in body proportions between individuals and populations. One major consequence of the revised Fully method is the ability to develop population specific mathematical stature estimations for archaeological populations, which has so far led to the development of formulae for Andean (Pomeroy and Stock, 2012), medieval Czech (Sládek *et al.*, 2015), Scandinavian (Maijanen and Niskanen, 2009), Polish (Vercellotti *et al.*, 2009) and European Holocene (Ruff *et al.*, 2012a) populations. Bidmos and Manger (2012) questioned the applicability of the revised Fully method, although their study was based on MRI images rather than direct osteometric data (for discussion see Brits *et al.*, 2017; Ruff *et al.*, 2012b). Although the anatomical method is most accurate, it requires a largely complete skeleton, and is therefore problematic in funerary contexts with high levels of disarticulation and fragmentation. Auerbach (2011) investigated the potential of estimating missing element dimensions through the revised Fully method (Raxter *et al.*, 2006), only successfully doing so with vertebral elements. As such, the application of the anatomical method was considered not suitable for this project.

5.2.2 Mathematical method

Mathematical methods rely on the relationship between individual or combined bone lengths and living stature, with dimensions of long bones and their correlation to stature central to the overall approach. The mathematical approach has a long history of study extending to the late 19th century (Pearson, 1899; Rollet, 1888), with Pearson (1899) setting a methodological framework that has remained largely unchanged since. A major limitation of mathematical methods, however, is that they do not account for variation in body proportions, for example lower limb length relative to trunk length, and therefore population specific equations are necessary. Ruff *et al.* (2012a) developed regression equations for European Holocene populations on the basis of accurate stature estimations using the revised Fully method (Raxter *et al.*, 2006, 2007). In doing so, Ruff *et al.* (2012a) demonstrated that previously available and widely used regression formulae (Formicola and Franceschi, 1996; Sjøvold, 1990; Trotter and Gleser, 1958) either overestimated or underestimated anatomical stature. Additionally, Ruff *et al.* (2012a) account for climatically driven differences in body proportions between northern and southern European groups, offering separate regression equations for northern and southern tibiae. Despite not accounting for body proportions, mathematical methods are applicable to isolated skeletal elements from commingled assemblages.

5.2.3 Stature estimation from fragmented elements

Within forensic literature, a range of methods have been developed to estimate stature from isolated and fragmented skeletal elements, consisting of *indirect* and *direct* methods. Direct methods estimate living stature from the fragmented element, whereas indirect methods involve a two-step approach that firstly achieves an estimated length of the bone before using that value to estimate stature (Bidmos, 2009). Early work by Steele and McKern (1969), using archaeological skeletal remains, and Steele (1970), using a modern forensic collection, developed a methodological approach that relied on anatomical landmarks and muscle attachments which since has been continually reviewed and revised (Jacobs, 1992; Simmons *et al.*, 1990; Wright and Vasquez, 2003). The main criticisms of Steele's (1969; 1970) method related to the difficulties in determining landmarks and the problematic choice of muscle attachments, which are highly variable (see Jacobs, 1992; Wright and Vasquez, 2003). Simmons *et al.* (1990) revised the Steele method for the femur due to its relationship with living stature and prevalence rates in forensic cases, replacing Steele's (1970) measurements with standard osteological measurements defined by Martin (1957).

However, the applicability of such methods to European archaeological populations is limited. Jacobs' (1992) study documented the inaccuracies of Steele's method when applied to prehistoric European populations, but argued towards retention of the underlying methodological approach and the need for more population specific equations. Few subsequent studies have been undertaken, with methods having only been developed for modern populations from India (Gayatri *et al.*, 2014; Kantha and Kulkarni, 2014; Mohanty *et al.*, 2012), south America (Wright and Vasquez, 2003) and south Africa (Bidmos, 2008, 2009; Chibba and Bidmos, 2007). As such, the methods that are currently available for estimating stature from fragmented skeletal elements were considered not appropriate for this study.

5.3 Body mass estimation methods

Estimating body mass, as defined by a combination of body fat and lean mass, in archaeological populations is more challenging, owing to its susceptibility to variation during life and because it is less directly related to skeletal structure than stature (Auerbach and Ruff, 2004; see Elliott *et al.*, 2015). Body mass estimation methods are divided into two approaches – ‘mechanical’ and ‘morphometric’. The morphometric approach estimates body mass by modelling the body as a cylinder through a combination of estimated stature and bi-iliac breadth (Auerbach and Ruff, 2004; Ruff *et al.*, 2005), and is generally considered most accurate in that it does not rely on the assumptions of the mechanical method, in addition to having been developed on a large and wide-ranging data set. As with the anatomical method for stature estimation, the morphometric approach requires an articulated individual and complete pelvis and is therefore not suitable on fragmented and commingled assemblages.

The mechanical method relies on the relationship between body mass and load-bearing skeletal structures. Femoral head breadth is most commonly used, although relationships between body mass and knee breadth (Ruff *et al.*, 2018; Squyres and Ruff, 2015) and long bone cross-sectional dimensions (Agostini and Ross, 2011; Pomeroy *et al.*, 2018; Ruff, 1990; Ruff *et al.*, 1991) have received renewed study and have been shown to provide reliable body mass estimates. In the early 1990s, a series of body mass equations using femoral head diameter were developed for modern North American (Ruff *et al.*, 1991), large bodied (Grine *et al.*, 1995) and small bodied (McHenry, 1992) populations, with a combination of these three methods being recommended for use on archaeological materials (Ruff *et al.*, 1997) with a downward correction factor of 10% to account for obesity in modern populations (Ruff *et al.*, 1991). In an attempt to overcome some of the issues of applying regression formulae developed on modern populations, Ruff *et al.* (2012a) developed specific equations for European Holocene groups based on bi-iliac breadth.

Both biomechanical and morphometric methods have been shown to yield similar results (Auerbach and Ruff, 2004; Ruff *et al.*, 2006a). In one example, Ruff *et al.* (2006a) showed considerable agreement between body mass estimations for Ötzi the Tyrolean Iceman derived from both mechanical and morphometric approaches, with both methods estimating his body mass at 61kg. However, some caution must be taken in the interpretation of body mass estimations, given the plasticity of both lean and fat mass in living individuals. A series of recent studies have tested a range of body mass estimation methods (Elliott *et al.*, 2015; Lacoste Jeanson *et al.*, 2017; Young *et al.*, 2018), demonstrating differences between true and estimated body mass in individuals of known weight. Furthermore, current body mass estimations for use on archaeological and forensic samples have been shown to not accurately represent the extremes of body mass, such as obesity or emaciation (Moore, 2008; Young *et al.*, 2018). In a combination of the mechanical and morphometric approaches, Junno *et al.* (2018) have suggested that body mass estimations from femoral head diameter can be improved by factoring in bone length or stature into regression equations. Within this chapter, body mass estimates were derived from regressions equations developed by Ruff *et al.* (2012a) and applied to isolated femora, and in some cases isolated femoral heads.

5.4 Materials and methods

5.4.1 Skeletal sample

The core data discussed here come from three Neolithic and five Copper Age samples (see Chapter Three for overview). Each individual sample represents an archaeologically and culturally distinct sample, allowing for investigation of spatial trends in body size within the individual Neolithic and Copper Age time periods (Table 5.5). Additional comparative data spanning the Late Upper Palaeolithic to the modern period was derived from Ruff *et al.* (2018c) and included in the analysis in order to explore long-term temporal trends in body size (see Chapter Three, Section 3.7).

5.4.2 Stature estimation

A mathematical method was chosen over other techniques as it can be readily applied to isolated skeletal elements and due to the availability of population specific equations. Stature for all individuals was estimated using maximum length of the femur and regression equations developed for European Holocene populations (Ruff *et al.*, 2012a). Although some of the Neolithic and Copper Age samples contained articulated individuals that would permit the use of combined femur and tibia estimations or anatomical methods, maximum femur length was chosen so that articulated individuals and commingled elements could be directly compared. The femur was chosen over the tibia because of its greater correlation with living stature (Trotter and Gleser, 1951; White *et al.*, 2011). Only femora from skeletally mature individuals without indications of major pathology were included in the analysis. Sex-specific equations were applied to femora from skeletons of known sex, which was only possible on articulated individuals from the central Italian Copper Age, Po Valley Copper Age, N. Italian and S. Italian Neolithic samples. Combined sex formulae for individuals of unknown sex were used for all other commingled samples as recommended by Ruff *et al.* (2012a). Although long bone reconstruction was used elsewhere in this study for bone length estimation for the purposes of locating diaphyseal cross-section location (see Chapter Four, Section 4.3.1), only complete bones were included in the analysis of stature presented in this chapter. Owing to the methodological challenges and complexities of comparing published stature data derived from other methods (Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016), only raw osteometric data was used in the comparative analysis (see Section 5.4.2).

5.4.3 Body mass estimation

Estimated body mass was derived from superior-inferior diameter of the femoral head using equations developed for European Holocene populations (Ruff *et al.*, 2012a). In cases where insufficient preservation of the femoral head did not allow for superior-inferior measurement, either anterior-posterior femoral head diameter or estimated femoral head diameter derived from shape fitting was used (see Chapter Four, Section 4.3.2). Whilst superior-inferior femoral head diameter is most appropriate for estimations of body mass in that it represents the orientation of weight bearing (Ruff *et al.*, 1991), the femoral head has been shown to be relatively circular in experimental and clinical contexts (Cereatti *et al.*, 2010; Kim, 1989; Parkinson, 2014) and therefore anterior-posterior diameter provides an accurate approximation. Whilst knee breadth (Ruff *et al.*, 2018; Squyres and Ruff, 2015) has been used to estimate body mass elsewhere in this study for the purposes of standardising diaphyseal cross-sectional geometric properties (see Chapters Six and Seven), the regression equations that are currently available have been developed on forensic reference collections from North America with larger body size. Current regression questions using knee breadth are therefore susceptible to the same problems that were identified by Ruff *et al*. (1994) for use of modern regressions derived from femoral head diameter and should only be used when absolutely necessary. As such, only body mass estimations derived from femoral head dimensions were included in the analysis presented here.

5.4.4 Statistical approach

Analysis of Variance (ANOVA) tests were conducted to explore spatial and temporal variation in body size between samples (Field, 2013) and all pairwise comparisons were primarily made using Hochberg GT2 *post-hoc* tests (Hochberg, 1974). The Hochberg GT2 test was chosen as it offers conservative pairwise comparisons when unequal sample sizes are present in the analysis (Stoline, 1981). Spatial variation between the individual Neolithic and Copper Age samples was investigated using one-way ANOVA and Games-Howell *post-hoc* tests due to unequal variances between samples (Games and Howell, 1976; Stoline, 1981). To explore temporal variation in body size, the individual Neolithic and Copper Age/Late Neolithic samples (i.e. Neolithic northern Italy, Copper Age Sardinia) were combined into their respective time periods and compared with body size data for the Upper Palaeolithic, Mesolithic, Bronze Age, Roman, Medieval and Modern periods. In the temporal analysis of overall body size trends, pooled sex comparisons that allowed for the inclusion of commingled assemblages were initially undertaken using one-way ANOVA tests with Hochberg GT2 *post-hoc* tests. To explore temporal differences between males and females, individuals of unknown sex were removed, and further statistical analysis was undertaken using one-way ANOVA and Hochberg GT2 *post-hoc* tests, with sex and time period as factors. Differences between adult males and females within each time period were investigated using independent *t*-tests. Box-and-whisker plots are used here to visualise the data, with the box component depicting the first and third quartiles and the whiskers representing the maximum and minimum values, with the exception of outliers which are plotted as separate points. All statistical analysis was conducted using SPSS Version 25. The threshold for statistical significance was set at <0.05 for all tests and exact p values for all tests are included in Appendix B (Tables B.1-B.4).

5.5 Results

In order to contextualise the results from the primary data collected in this study and to explore long-term trends in body size in central Mediterranean prehistory, comparisons are first made with a large sample of individuals isolated from the Ruff (2018c) dataset spanning the southern European Palaeolithic and Mesolithic, and the Italian Bronze, Roman, Medieval and Modern periods (see Chapter Three, Section 3.7). The results of the focused spatial analysis of coeval Neolithic and Copper Age samples from Malta, Sardinia and the Italian peninsula are discussed second.

5.5.1 Temporal trends in body size

Table 5.1: Summary statistics for temporal trends in estimated body mass (Kg) and estimated stature (cm) by sex and time period.

	Body mass (Kg)			***Stature (cm)***		
	Mean	**St.D.**	***N***	**Mean**	**St.D.**	***N***
Pooled sex w/disarticulated samples						
Upper Pal.	65.9	7.6	28	164.0	9.3	30
Mesolithic	67.6	6.7	26	164.9	9.2	30
Neolithic*	53.3	8.0	43	154.3	6.0	44
Copper Age*	57.7	7.8	108	158.5	7.9	90
Bronze Age	60.7	7.1	33	160.2	8.5	33
Roman	55.0	9.9	39	158.3	7.1	45
Medieval	62.6	7.6	42	162.1	8.9	49
Modern	58.0	8.7	32	157.2	7.7	33
Males						
Upper Pal.	68.9	6.8	17	167.4	9.0	17
Mesolithic	68.8	6.3	20	167.4	8.5	22
Neolithic	55.9	9.7	20	156.7	6.6	18
Copper Age	58.7	5.7	24	162.5	4.5	19
Bronze Age	64.2	6.9	17	165.7	6.4	17
Roman	56.4	11.2	20	160.8	5.1	23
Medieval	66.2	6.9	25	166.6	8.2	27
Modern	60.6	8.4	22	160.4	5.5	22
Females						
Upper Pal.	61.3	6.6	11	159.5	7.9	13
Mesolithic	63.4	6.7	6	158.1	7.9	8
Neolithic	52.7	5.4	11	151.4	4.7	11
Copper Age	52.7	5.8	13	152.8	5.2	11
Bronze Age	57.1	5.4	16	154.5	6.4	16
Roman	53.5	8.2	19	155.8	8.1	22
Medieval	57.3	5.1	17	156.7	6.5	22
Modern	52.3	6.7	10	151.0	7.9	11

*Sample contains disarticulated individuals without determined sex.

Summary statistics for temporal trends in body mass and stature are presented in Table 5.1 and the results of the one-way ANOVA tests investigating pooled sex comparisons in body size between time periods are presented in Table 5.2. Box-and-whisker plots showing temporal differences in body mass and stature are presented in Figure 5.1 and Figure 5.2. The results of the one-way ANOVA tests and *post-hoc* comparisons exploring diachronic trends in body size between males and females are presented in Table 5.3, whilst the results of the independent *t*-

tests comparing body size variables between males and females within individual time periods are presented in Table 5.4.

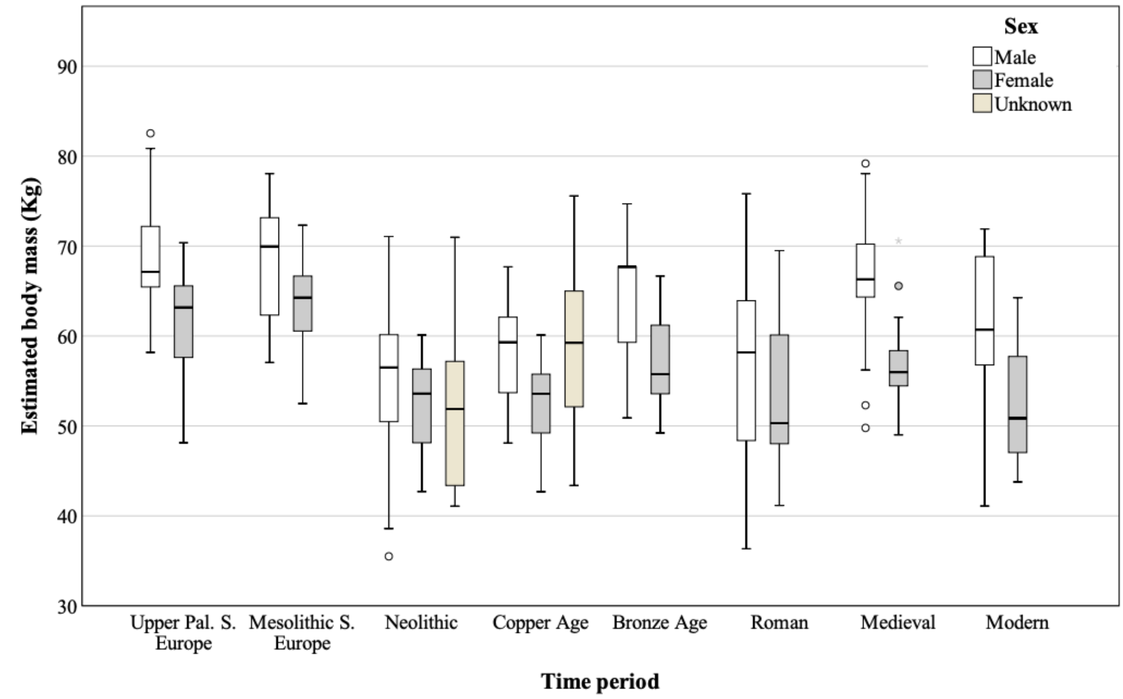


Figure 5.1 – Box-and-whisker plots showing temporal trends in estimated body mass (Kg) from the Upper Palaeolithic to the Modern Period in the central Mediterranean.

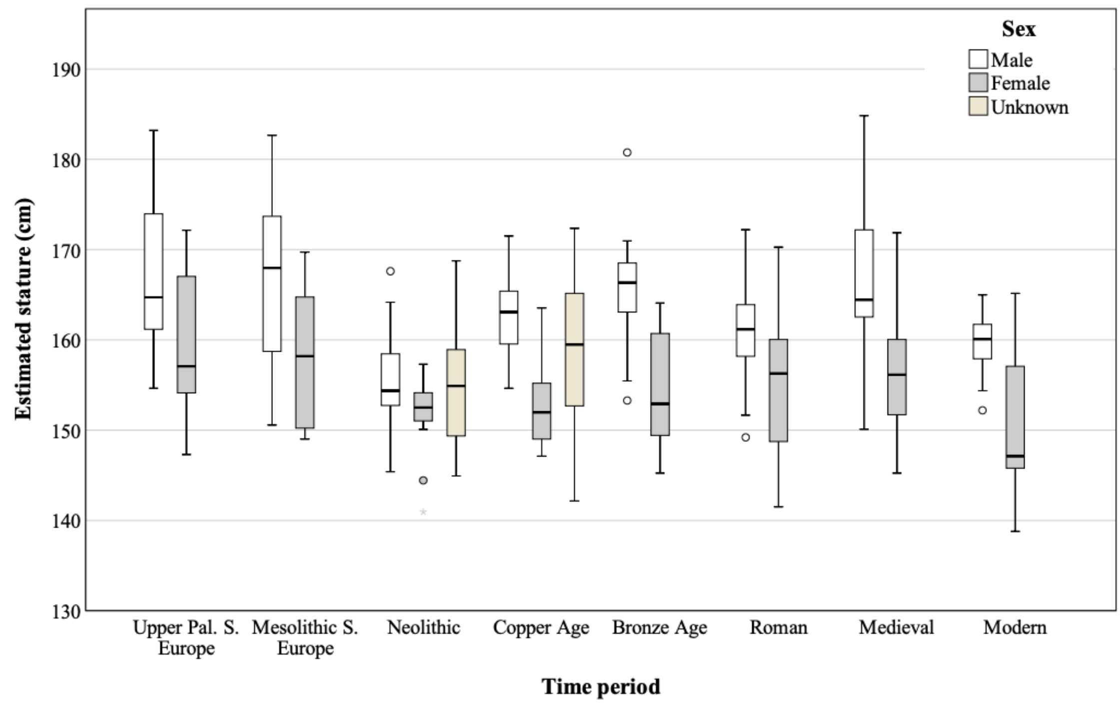


Figure 5.2 – Box-and-whisker plots displaying temporal trends in estimated stature (cm) from the Upper Palaeolithic to the Modern Period in the central Mediterranean.

The results show relative consistency in body size between the Upper Palaeolithic and Mesolithic, which was followed by a significant reduction in body size during the transition to agriculture, with the Neolithic sample having significantly reduced stature ($p<0.001$) and body mass ($p<0.001$) than pre-agricultural groups (Table 5.2; Figure 5.1; Figure 5.2). The trend of decreased body size continued into the Copper Age where only a modest numeric increase is observed (Table 5.1; Figure 5.1; Figure 5.2), although a subsequent significant increase in body mass ($p=0.002$) and stature ($p=0.041$) occurred in the Bronze Age. On consideration of sex-based comparisons, the results show that a divergence in body size between males and females took place during the Copper and Bronze Ages (Table 5.4; Figure 5.1; Figure 5.2). After the Neolithic, both stature and body mass increased in males, whilst female body size remained consistently low. Following an increase in body size in the Bronze Age, body mass remained highly variable thereafter, whereas stature remained more stable. These results reflect, in part, an overall consistency in stature, particularly among females (Table 5.3). A second numeric, but not statistically significant, decline in body mass ($p=0.066$) and stature ($p=1.000$; Table 5.1; Figure 5.1; Figure 5.2) occurred during the Roman period, where body size values decreased to levels comparable with the Copper Age (Table 5.1). Body mass then significantly increased ($p<0.001$) in the Medieval period, although stature only increased modestly (Table 5.1), with both body size components not differing significantly in the Modern period (Table 5.2). The subsequent increase in body size following the Roman period, as with the Neolithic, is characterised by a lag among women (Figure 5.1; Figure 5.2).

Table 5.2: Results of one-way ANOVA and post-hoc[b] comparisons exploring temporal trends in body size.

Time period	***Body mass (Kg)***			***Stature (cm)***		
	Sig. *post-hoc* difference[a,b]			Sig. *post-hoc* difference[a,b]		
Upper Pal.	NEO, CA, RO, MOD			NEO, CA, MOD		
Mesolithic	NEO, CA, BA, RO, MOD			NEO, CA, BA, RO, MOD		
Neolithic	UP, MESO, BA, MED			UP, MESO, MED		
Copper Age	UP, MESO, MED			UP, MESO		
Bronze Age	MESO, NEO			NEO		
Roman	UP, MESO, MED			MESO		
Medieval	NEO, CA, RO			NEO		
Modern	UP, MESO			UP, MESO		
ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
Time period	7	13.7	<0.001	7	7.42	<0.001

[a] Alpha = <0.05. [b] Post-hoc tests using Hochberg GT2, exact *p* values presented in Table B.1 in Appendix B.
UP = Upper Palaeolithic, MESO = Mesolithic, Neo = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

The sex-based comparisons demonstrate that stature was consistently greater in males throughout the Upper Palaeolithic to Modern periods, whilst body mass was less consistent with no significant difference reported between males and females in the Mesolithic, Neolithic and Roman periods (Table 5.4; Figure 5.1; Figure 5.2). As reflected in the standard deviations (Table 5.1) and box-and-whisker plots presented in Figure 5.1 and Figure 5.2, there is considerable variation in body mass and stature among the individuals of unknown sex within the Neolithic and Copper Age time periods, reflecting the presence of both males and females within the sample. This similar pattern is further reflected in the pooled sex summary statistics presented in Table 5.1.

Table 5.3: Results of one-way ANOVA and post-hoc[a] comparisons exploring temporal differences in body size by time period and sex.

Time period		***Body mass (Kg)***		***Stature (cm)***	
		Sig. *post-hoc* difference[a,b]		Sig. *post-hoc* difference[a,b]	
Upper Pal.	Male	NEO, MOD		NEO, CA, RO, MOD	
	Females	CA, RO, MOD			
Mesolithic	Male	NEO, MOD, RO		NEO, CA, RO, MOD	
	Females	NEO, CA, RO, MOD		NEO	
Neolithic	Male	UP, MESO, MED		UP MESO, MED	
	Females	MESO		MESO	
Copper Age	Male	MESO, MED		UP, MESO, MED	
	Females	UP, MESO			
Bronze Age	Male			NEO	
	Females				
Roman	Male	MESO		UP, MESO, MED	
	Females	UP, MESO			
Medieval	Male	NEO, CA, RO		NEO, MOD	
	Females				
Modern	Male	UP, MESO		UP, MESO, MED	
	Females			UP, MESO	
ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
Male	7	9.784	<0.001	7	7.257	<0.001
Female	7	4.277	<0.001	7	2.297	0.032

[a] Alpha = <0.05. [b] *Post-hoc* tests are Hochberg GT2, exact *p* values presented in Tables B.2 and B.3 in Appendix B.
UP = Upper Palaeolithic, MESO = Mesolithic, Neo = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

Table 5.4: Results of independent t-tests investigating differences in body size between males and females within time periods.

	Body mass (Kg)	Stature (cm)
	p*	p*
Upper Pal.	**0.007**	**0.017**
Mesolithic	0.082	**0.012**
Neolithic	0.191	**0.003**
Copper Age	**<0.001**	**<0.001**
Bronze Age	**0.003**	**<0.001**
Roman	0.370	**0.019**
Medieval	**<0.001**	**<0.001**
Modern	**0.009**	**0.003**

*Alpha = <0.05. All significant differences are highlighted in bold and indicate greater values in males.

5.5.2 Spatial trends in the Neolithic and Copper Age

Table 5.5: Summary statistics for the analysis of spatial trends in estimated body mass (Kg) and stature (cm) within the Neolithic and Copper Age.

Sample	Body mass (Kg)			Stature (cm)		
	N	Mean	St.D.	N	Mean	St.D.
Pooled sex w/disarticulated samples						
Neolithic N. Italy*	25	53.8	8.4	22	153.2	5.7
Neolithic S. Italy	9	53.3	6.5	9	156.3	5.0
Neolithic Sardinia*	9	52.0	9.2	13	154.9	7.0
Copper Age c. Italy*	31	56.1	6.2	26	158.3	6.7
Copper Age Po Valley	10	59.2	6.8	8	161.1	5.1
Late Neolithic Malta*	28	58.6	6.8	22	160.7	7.7
Copper Age Sardinia*	27	55.7	9.2	26	156.0	9.1
Alpine Beaker*	12	62.9	9.3	8	158.3	8.7
Males						
Neolithic N. Italy	15	55.4	9.4	13	155.0	4.7
Neolithic S. Italy	4	53.1	7.8	4	158.2	7.4
Copper Age central Italy	17	58.9	5.3	14	162.7	4.4
Copper Age Po Valley	7	58.1	7.0	5	162.0	5.2
Females						
Neolithic N. Italy	7	52.8	5.1	7	149.6	5.0
Neolithic S. Italy	4	52.5	6.8	4	154.5	2.1
Copper Age central Italy	13	52.7	5.8	11	152.8	5.2

*Contains disarticulated skeletons.

Summary statistics for stature and body mass in the individual Neolithic and Copper Age samples are presented in Table 5.5. Results for spatial differences within the central Mediterranean are presented in Table 5.6. Only the Neolithic N. Italy, Neolithic S. Italy and central Italian Copper Age samples contain both males and females (Table 5.5). As sex-based comparisons of these groups are discussed in the preceding section, pooled sex comparisons were undertaken so as to enable inclusion of commingled samples. Box-and-whisker plots for body mass (Kg) and stature (cm) are presented in Figure 5.3 and Figure 5.4 respectively. The results of the one-way ANOVA and *post-hoc* tests revealed few significant differences between groups, although some underlying trends in the data can be gleaned from consideration of the summary statistics. In general, both body mass and stature are lower in the Neolithic groups, reflecting the broader temporal trends discussed above (see Section 5.5.1). Of all the groups, the Copper Age Po Valley, Alpine Bell Beaker and Late Neolithic Malta groups have largest mean body masses and statures (Table 5.5; Figure 5.3; Figure 5.4). In particular, the Copper Age Po Valley (p=0.040) and Late Neolithic Maltese samples (p=0.014) had significantly greater average stature than the N. Italian Neolithic sample, who display the lowest average stature of all groups (Table 5.5; Table 5.6). Focusing on Sardinia, whilst no significant difference between body size variables is seen between the Neolithic and Copper Age, a slight increase in both stature and body mass is observed (Table 5.5; Figure 5.3; Figure 5.4). The standard deviations also show that variation in stature and body mass values is comparable across all groups (Table 5.5).

Table 5.6: Results of one-way ANOVA and post-hoc[b] comparisons exploring spatial trends in body size.

Time period	***Body mass (Kg)*** Sig. *post-hoc* difference[a,b]			***Stature (cm)*** Sig. *post-hoc* difference[a,b]		
Neolithic N. Italy				LNM, CAPV		
Neolithic S. Italy						
Neolithic Sardinia						
Copper Age c. Italy				NE0NI		
Copper Age Po Valley				NE0NI		
Late Neolithic Malta						
Copper Age Sardinia						
Alpine Beaker						
ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
Time period	7	2.766	0.010	7	2.443	0.022

[a] Alpha = <0.05. [b] Post-hoc tests using Games-Howell, p values presented in Table B.4 in Appendix B.

NEONI = Neolithic N. Italy, NEOSI = Neolithic S. Italy, NEOSA = Neolithic Sardinia, CACI = Copper Age central Italy, CAPV = Copper Age Po Valley, LNM = Late Neolithic Malta, CAS = Copper Age Sardinia, APB = Alpine Beaker.

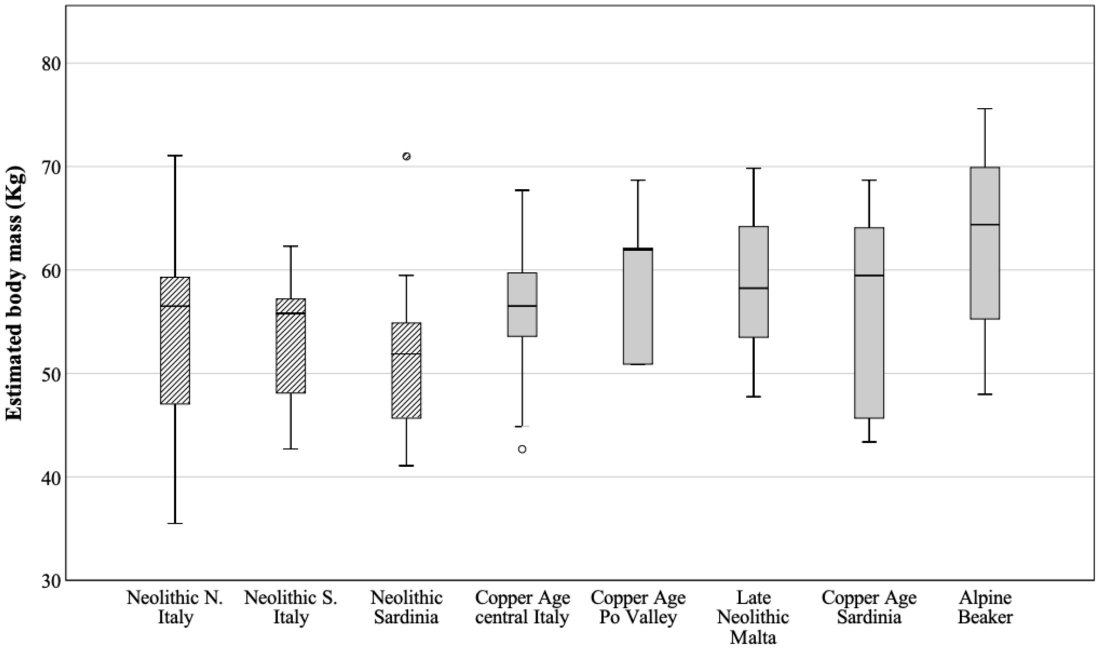


Figure 5.3 – Box-and-whisker plots showing spatial variation in estimated body mass (Kg) between the pooled sex Neolithic and Copper Age/Late Neolithic samples analysed in this study (samples ordered chronologically, Neolithic are denoted with diagonal lines).

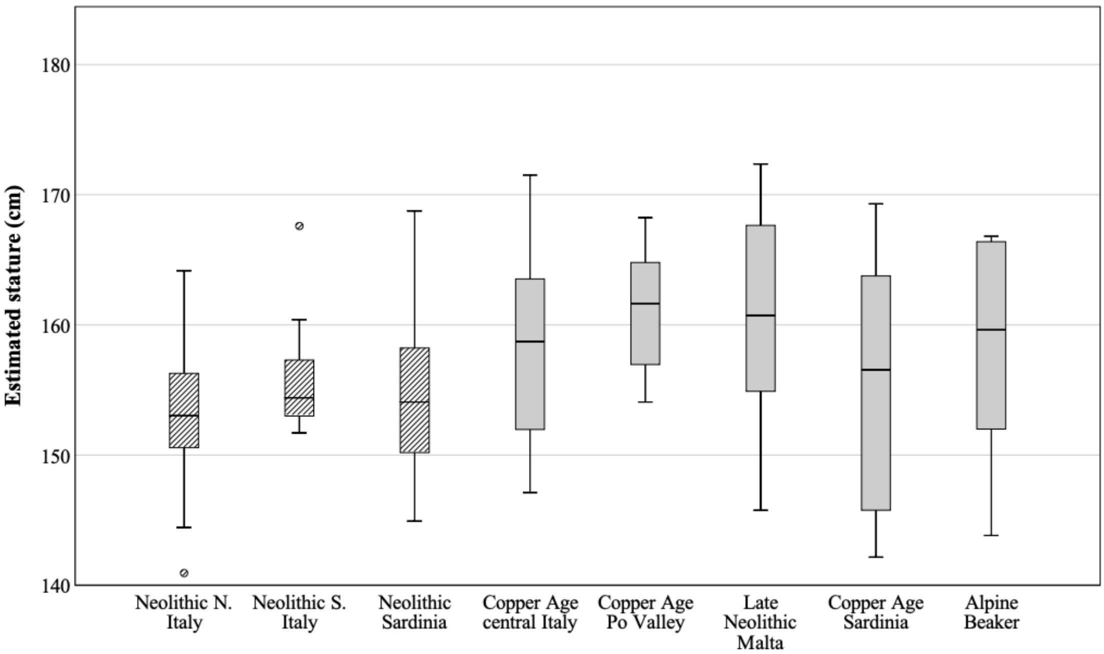


Figure 5.4 – Box-and-whisker plots showing spatial variation in estimated stature (cm) between the pooled sex Neolithic and Copper Age/Late Neolithic samples analysed in this study (samples ordered chronologically, Neolithic groups denoted with diagonal lines).

5.6 Discussion

The results show that body size fluctuated considerably over the ca. 24,000 years represented in this chapter, but that within the individual Neolithic and Copper Age time periods there was relative spatial homogeneity in body size. Significantly, both stature and body mass fluctuated in relative agreement to one another, although temporal variation in stature was less erratic. It is also noteworthy that the pronounced reductions in both body mass and stature that occurred following the transition to agriculture and during the Roman period were followed by a gradual recovery over the course of subsequent time periods. Interpreted within a life history framework, the results from the Neolithic and Roman period are suggestive of considerable growth impairment and physiological stress during times of important social and economic change (i.e. Macintosh *et al.*, 2016). As might be expected, males had consistently larger body size than females in all time periods; however, the results also show increased sexual dimorphism in body size variables during the Copper and Bronze Ages, and the Medieval period. The divergence in body size between males and females at these two points in time is characterised by delayed recovery in both stature and body mass among women.

5.6.1 Temporal trends in body size

The temporal analysis of body size highlighted marked changes in stature and body mass from the Upper Palaeolithic to the Modern period. As expected, the pooled sex analysis showed that body size decreased following the transition to agriculture. The reduction in body size during the Neolithic was followed by a gradual recovery over the duration of the Copper Age and Bronze Age, before subsequent deviations in the Roman period and Modern periods. The results are somewhat similar to those recently reported by Holt *et al.* (2018b) and Niskanen *et al.* (2018), where the pre-agricultural and post-Bronze Age comparative data used in this study originate. Although Holt *et al.*'s (2018b) discussion on body size in France and Italy contains a robust sample of individuals from pre-agricultural time periods, and from the Bronze Age onwards, their analysis is hampered by a lack of Neolithic and Copper Age samples, which the present study provides. Holt *et al.*'s (2018b) study does include nine of the 15 individuals from Fontenoce-Recanati analysed as part of this study (see Chapter Three, Section 3.5.2), although they are grouped into a broad "Neolithic France and Italy" category with samples from central France, rather than in a separate Copper Age group. The analysis presented in this chapter, which reveals a divergence in male and female body size in the Copper Age (see below), highlights the importance of distinguishing between the Neolithic and Copper Age, especially with respect to Italy, where the latter accounts for almost 2,000 years of prehistory.

The marked decline in body size following the transition to agriculture, and subsequent gradual recovery, follows the classic trend seen throughout Europe (Ehler and Vančata, 2009; Macintosh *et al.*, 2016; Niskanen *et al.*, 2018; Piontek and Vancata, 2012), North Africa (Stock *et al.*, 2011) and North American (Larsen, 2015; Latham, 2013; Mummert *et al.*, 2011). Reduced body size during the Neolithic suggests that the transition to agriculture triggered an overall period of growth impairment and increased physiological stress, resulting from decreased dietary diversity, the aggregation of human groups into larger settlements, and heightened exposure to zoonotic diseases with the development of animal husbandry (Cohen and Armelagos, 1984; Larsen, 2015). In the case of the central Mediterranean, Early Neolithic settlement was dense and nucleated (see Chapter Two), either within villages or occupation in caves, and faunal assemblages generally show limited diversity and little exploitation of wild resources (Barker, 1999; Pearce, 2013; Vander Linden and Silva, 2018), although Sardinia is an exception (Malone, 2003; Ucchesu *et al.*, 2017; Vander Linden and Silva, 2018). Although Niskanen *et al*. (2018) demonstrated that decreased body size following the transition to agriculture was not a universal trend, the results of this chapter suggest that within the central Mediterranean the discernible economic transformation with the onset of the Neolithic resulted in an overall smaller body size that is indicative of heightened physiological stress and growth impairment among early agricultural societies.

The gradual recovery in body size with the onset of the Copper Age suggests that established agricultural societies in the central Mediterranean did not experience the same degree of physiological stress as early agricultural societies, supporting the second expectation outlined in Section 5.1.2. Robb (1994c) suggested that central Mediterranean Copper and Bronze Age groups might have had good nutritional status due to increased consumption of meat and secondary dairy products. Increased consumption of dairy products is one plausible explanation for the general improvement in nutritional status during the Metal Ages, with the Copper Age showing evidence for the introduction of secondary products (Barker, 1999; Cazzella and Guidi, 2011). However, Neolithic groups in northern Italy and France also display evidence for increased consumption of terrestrial animal proteins (Le Bras-Goude *et al.*, 2006, 2010; Salazar-García *et al.*, 2018), suggesting that the dietary trends proposed by Robb (1994c) are not exclusive to the Copper Age. Thus, the recovery in body size after the Neolithic may also relate to other aspects of Copper and Bronze Age society. The shift away from dense and nucleated settlement to more dispersed settlement patterns during the Copper Age (Dolfini, 2015), alongside increasing specialisation of herding practices (Barker, 1999), may have also removed some of the factors affecting body size, such as lessening exposure to zoonotic diseases during the Metal Ages.

The sex-based comparisons showed that a divergence in body size (both stature and body mass) between men and women occurred during the Copper and Bronze Ages as part of an overall delayed recovery in body size among women following the transition to agriculture. Throughout the Copper and Bronze Ages, body size among females remained the same, whilst male body size increased at a greater rate. The results differ from those reported for central-southern Europe, where sexual dimorphism in body size decreased following the Neolithic (Macintosh *et al.*, 2016), and could reflect gender inequality during the Copper Age and Bronze Age that negatively impacted on female nutritional status. This result is reflective of the broader trends in body size, with female body size exhibiting greater stability over time, in contrast to males.

The central Mediterranean Copper Age is traditionally associated with increasing archaeological evidence for the emergence of gendered society and binary social differentiation between men and women that was then reaffirmed in the Bronze Age (Cocchi Genick, 2004; Robb, 1994b, 1994c; Whitehouse, 2001). It is therefore tempting to interpret the divergence in male and female body size within this framework, but this scenario is not supported in the analysis of habitual manual activity presented in the following chapter (see Chapter Six), which shows no evidence for sexual division of labour in the Copper Age. However, the divergence in body size does coincide with increased asymmetry in humeral length among agriculturalist females, which is also reflective of developmental stress (see Chapter Six, Section 6.5.2). Nutritional differences between males and females may be expected to be reflected in dietary variation, however, the results from the analysis of body size are not supported by palaeodietary studies, which show no difference between the sexes during the Italian Copper Age (De Angelis *et al.*, 2019) and Bronze Age (Lai *et al.*, 2013; Tafuri *et al.*, 2009, 2018; Varalli *et al.*, 2016). It is important to acknowledge that few systematic studies of palaeodiet have been published for the Copper Age in the Italian peninsula - although ongoing research by Italian scholars is actively addressing this issue.

Instead, the relative stability of female body size, in contrast to males, across the ca. 24,000 years represented by this study could be explained by sex-based differences in response to nutritional stress. Research on both living (Stini,1969; Stinson, 1985) and archaeological (Sparacello *et al*., 2017b; Vercellotti *et al*., 2011) individuals indicates that males show greater susceptibility to instances of physiological stress, whilst females appear less sensitive to changing environmental conditions. Sparacello *et al*.'s (2017b) comparison of stature between high and low status individuals, inferred from burial assemblages, in central Italian Iron Age groups demonstrated that higher status males exhibited greater average stature than low status males, whereas females showed no differences in stature. These sex-based differences in susceptibility to environmental conditions result in more modest changes in female body size in response to physiological stress and may explain the long-term trends in female body size observed in the results.

The interpretation of stature and body mass in prehistory is reinforced through comparisons with later time periods, where the factors influencing body size are better understood. A second decline in stature and body mass occurred during the Roman period and was followed by a subsequent recovery in the Medieval period. This trend has previously been reported for the central Mediterranean region (Floris *et al.*, 2012; Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016; Holt *et al.*, 2018b) and wider Europe (Danubio *et al.*, 2017; Gowland, 2017; Macintosh *et al.*, 2016; Martella *et al.*, 2016; Walter, 2017). The Roman period brought with it fundamental and widespread socio-economic change on a scale that was arguably not seen since the transition to agriculture. The advent of urbanism, increased population density, migration and social and political complexity have all been argued to have contributed to a general reduction in health that was seen throughout Europe in the Roman period (Gowland, 2017; Killgrove, 2014). Therefore, it is unsurprising that the two most pronounced declines in body size occurred during two of the most significant points of social and economic transition over the 24,000 years represented in this study.

The small body size during the Modern period (comparable to the Neolithic and Roman periods) can be explained through the composition of this sample, which consists of two 19th century assemblages from Syracuse, in Sicily, and Sassari, in Sardinia (Holt *et al.*, 2018b). Sicilian populations during 18th and 19th centuries had average statures closer to mainland Italy (Hatton and Bray, 2010; Pes *et al.*, 2017), but average Sardinian height has until recently been among the shortest in Europe (Pes *et al.*, 2017; Zoledziewska *et al.*, 2016). Both the Sicilian and Sardinian sites are considered as representing individuals from lower socioeconomic circumstances (Holt *et al.*, 2018b), which when considered within the life history framework discussed above, may also cause decreased body size among these samples. In a comprehensive review article, Pes *et al*. (2017) argued that the small average stature of Sardinian populations was the result of endemic infectious disease, malaria and physiological stress. These environmental conditions were not alleviated until after the Second World War, when an increase in average stature among Sardinians is then documented (Pes *et al.*, 2017). It is likely that the environmental factors affecting stature among Sardinians were similar to those in Sicily (Snowden, 2008). Therefore, the Modern period data used in this study are likely not representative of the average height of modern populations from the wider central Mediterranean area.

Although direct comparisons with studies using differing body mass and stature estimation methods are problematic (Elliott *et al.*, 2015; Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016), the results show that body mass and stature in the central Mediterranean Neolithic and Copper Age fall below the overall averages reported for the European Neolithic (Niskanen *et al.*, 2018; Piontek and Vancata, 2012) and Late Neolithic/Copper Age (Ehler and Vančata, 2009; Macintosh *et al.*, 2016; Sládek *et al.*, 2006), as well as those previously documented for the Italian Neolithic (Robb, 2007). Both Macintosh *et al.* (2016) and Niskanen *et al.* (2018) used the same stature and body mass estimation methods as this study, and in general the results presented here support the growing body of evidence that southern European individuals had smaller stature from the Neolithic onwards (Holt *et al.*, 2018b; Niskanen *et al.*, 2018; Ruff *et al.*, 2012a). The results also show that the body mass and stature estimates for Ötzi the Iceman reported by Ruff *et al.* (2006a), at 61kg and 158cm, fall within with average stature (162.5 ± 4.5 cm) and body mass (58.7±5.7 Kg) estimates for Italian Copper Age males (Table 5.1). When recalculated using the regression formulae subsequently developed by Ruff *et al.* (2012a) for European Holocene males, on the basis of his superior-inferior femoral head diameter (44.3mm), Ötzi's body mass is estimated at 57.34Kg - still within the average range for Copper Age Italian males, indicating that he conforms to typical Italian, rather than central-northern European, Copper Age body size.

5.6.2 Spatial trends in the Neolithic and Copper Age

The spatial uniformity in body size between the Neolithic and Copper Age samples suggests that the environmental and nutritional factors influencing stature and body mass were relatively similar during these two periods. Palaeodietry evidence does show relative homogeneity in diet across the central Mediterranean during 4^{th}-3^{rd} millennium BC, with reliance on terrestrial protein resources (Cianfanelli *et al.*, 2015; De Angelis *et al.*, 2019; Lai, 2008, 2015; Martinez-Labarga *et al.*, 2016; Poggiani-Keller *et al.*, 2016; Richards *et al.*, 2001); however, some variation is seen in Adriatic central Italy (De Angelis *et al.,* 2019) and Sardinia (Lai 2008, 2015). Zooarchaeological assemblages indicate widespread reliance on mixed agriculture throughout the Italian peninsula during the 4^{th}-3^{rd} millennia BC, but also evidence for the development of small scale transhumant systems and secondary products as the Copper Age progressed (Barker, 1999, 2005; Robb, 2007; Tecchiati *et al.*, 2013). For the Neolithic, whilst some latitudinal variation is seen in zooarchaeological assemblages (Vander Linden and Silva, 2018), faunal and palaeodietary evidence indicates that Neolithic diet was fundamentally based upon terrestrial resources and consistent throughout the central Mediterranean (Craig *et al.*, 2006; Le Bras-Goude *et al.*, 2006; Martinez-Labarga *et al.*, 2016; Tagliacozzo, 2005) (see Chapter Two, Section 2.3). The general consistency of the zooarchaeological and palaeodietary data within the Neolithic and Copper Age ultimately corroborates the results of the body size analysis and suggests that the nutritional status of coeval prehistoric groups within the central Mediterranean was fundamentally uniform.

Whilst no statistically significant difference was observed in the spatial analysis of body size within the individual Neolithic and Copper time periods, the greatest average stature is seen in the Late Neolithic Maltese, Alpine Beaker and Copper Age Po Valley samples. The higher values in the Alpine and Po Valley samples are to be expected, given that both assemblages are largely male dominated (Bertoldi *et al.*, 2012; Miari, 2014; Poggiani-Keller *et al.*, 2016; see Chapter Three, Section 3.4.2-3.4.3); however, the results for Late Neolithic Malta are surprising, given the small island context of the sample where smaller body size might be expected (Foster, 1964). Insular dwarfism has been documented in modern human populations (Berger *et al.*, 2008; Diamond, 2004), although socio-economic factors have also been shown to affect this process (Stock and Migliano, 2009). In this respect, the increased body size values of the Maltese sample contradict the social and economic models that have been proposed for the Maltese Late Neolithic *Tarxien* phase, which place emphasis on themes of population stress (pers. comm., McLaughlin, T.R. 2018; Stoddart *et al.*, 2009), sustainability, declining health and societal collapse (Trump, 2002).

The results for Neolithic and Copper Age Sardinia are also interesting, as the geographically constrained island context presents an opportunity to make a direct temporal comparison. Whilst there is a slightly more noticeable increase in body mass between the Sardinian Neolithic and Copper Age samples, the consistency in stature over time differs from the overall trend seen throughout the central Mediterranean. Dietary stable isotope studies that have been undertaken on the Sardinian samples analysed in this chapter documented decreased consumption of terrestrial animal protein among the Late Copper Age sample (Lai, 2008; Lai, 2015). However, the analysis of body size suggests that these dietary differences did not have an impact on nutritional status. Pes *et al.'s* (2017) review of the factors influencing body size in Sardinian populations from prehistory to the modern period argued that the stature of prehistoric Sardinians was below that of coeval groups. The results presented here contest this, demonstrating that Sardinian body size during the Neolithic and Copper Age was typical for the central Mediterranean at this time.

5.7 Conclusion

This chapter has examined temporal and spatial trends in adult body mass and stature in the central Mediterranean Neolithic and Copper Age, placing the results within the context of ca. 24,000 years of body size trends, and available dietary and archaeological evidence. Unfortunately, the interpretations of the data presented here are hampered not only by the fact that much of the skeletal record consists of fragmented and disarticulated assemblages, but also by a lack of widespread, detailed and systematic comparative bioarchaeological research on diet and skeletal indicators of nutrition for the Copper Age. Of most note is the increased sexual dimorphism in body size variables between males and females during the Copper and Bronze Age, which appears to signal the establishment of gender inequality that negatively impacted on nutritional status among women. Interestingly, this trend is not supported by published palaeodietary studies or the biomechanical evidence presented in the following chapter (see Chapter Six). Therefore, in order to fully explore this trend, future research must be directed towards analysis of skeletal indicators of stress and stable isotopes in Italian Copper Age populations, and increased emphasis must be placed on interpreting bioarchaeological data within a social framework, as well as an economic one. Regardless, the findings of this chapter have identified important trends that add to our understanding of body size, health and nutrition over the course of central Mediterranean prehistory. Previous studies that have sought to investigate temporal and spatial trends in body size within the central Mediterranean have either suffered from a lack of adequate or representative samples for all time periods, poorly defined chronology (Floris *et al.*, 2012; Holt *et al.*, 2018b) or methodological limitations (Giannecchini and Moggi-Cecchi, 2008; Martella *et al.*, 2016). Through analysis of a large sample of chronologically secure Neolithic and Copper Age individuals, the results of this chapter complement the comprehensive overview of body size for Italy and France provided by Holt *et al*. (2018b), revealing important fluctuations in body size and evidence for physiological stress during times of crucial social, economic and cultural transition.

An important future step for central Mediterranean bioarchaeology will be the continued application of ancient DNA. In particular the examination of genomic height as has been undertaken for prehistoric Iberia (Martiniano *et al.*, 2017) and wider Europe (Cox *et al*., 2019) will enable a robust assessment of the interpretations presented here. It is difficult to establish on the basis of current evidence whether the samples represented in this study can be considered genetically analogous and whether there is potential to explore the relationship between population history and body size. However, the congruence between the long-term trends in both stature and body mass, which has historically been considered to be under less genetic control, suggests that any potential genotype-phenotype associations are likely to be weak, and instead supports the life history framework adopted here. In spite of the debates surrounding the relationship between body size, genetic and non-genetic factors, it is interesting to note the timing of the two most pronounced declines in body size over the ca. 24,000 years covered in this study. Body size declined during the Neolithic and Roman periods, which were two profound episodes of social and economic change that saw major changes in subsistence strategy, settlement patterns and social transformation that evidently took their toll on the individuals that experienced them.

6 MANUAL BEHAVIOUR, SOCIAL CHANGE AND ECONOMIC DIVERSIFICATION: UPPER LIMB CROSS-SECTIONAL GEOMETRY

6.1 Introduction

Long bone morphology has been shown to represent, at least in part, adaptations to mechanical strain associated with habitual behaviour, enabling archaeologists to reconstruct patterns of physical activity in past populations. Whilst skeletal morphology is influenced by a wide range of genetic, environmental, hormonal and age related factors (Holt and Agostini, 2018; Kini and Nandeesh, 2012; Macintosh *et al*., 2018), experimental studies have demonstrated that bone tissue adapts and remodels to *in vivo* mechanical loading (Biewener *et al.*, 1983; Lanyon, 1984; Lanyon and Baggott, 1976; Lanyon *et al.*, 1982; Simkin *et al.*, 1989), and in a manner consistent with particular patterns of habitual behaviour (Macintosh and Stock, 2019; Shaw and Stock, 2009a, 2009b; Stock and Pfeiffer, 2001; Ruff, 2019). This process, termed "bone functional adaptation" (Ruff *et al*., 2006b), sees the distribution of new cortical bone tissue in response to mechanical stimuli, and can be examined through a biomechanical approach that applies mechanical principles to biological materials in order to understand their form and function (Hart *et al.*, 2017; Ruff, 2019). Skeletal biomechanics has been most widely applied to understanding structural remodelling of the long bones through the application of beam theory (Huiskes, 1982). By modelling the long bones as structural beams and estimating the cross-sectional geometric properties (henceforth "CSG properties") related to bone strength and bending rigidity, estimates of the intensity and direction of mechanical loading on the human skeleton related to repetitive behaviours can be made. This allows biological anthropologists to reconstruct patterns of physical activity in past and living populations (Larsen, 2015; Ruff, 2019; Ruff and Hayes, 1983a).

Upper limb CSG properties have been extensively used to investigate spatial and temporal trends in manual physical activity in a range of contexts (Barbieri *et al.*, 2017; Cameron and Pfeiffer, 2014; Kubicka *et al.*, 2018; Macintosh *et al*., 2014a, 2017; Marchi *et al.*, 2006; Rhodes and Knüsel, 2005; Ruff *et al.*, 1993, 2015; Saponetti and Scattarella, 2003; Sládek *et al.*, 2007; Sparacello and Marchi, 2008; Spencer *et al.*, 2012; Stock and Pfeiffer, 2001; Weiss, 2009; Wescott and Cunningham, 2006), as well to understand the effects of pathology (Sparacello *et al.*, 2016), ontogeny (Blackburn, 2011), marine mobility behaviours (Stock and Pfeiffer, 2001; Weiss, 2003) and socio-economic change (Macintosh *et al*., 2014a; Marchi *et al.*, 2006; Sládek *et al.*, 2007; Sparacello *et al.*, 2011, 2015) on the morphology of the humerus. Within the field of long bone biomechanics, different cross-sectional properties have been used to explore the mechanical competence of bone tissue, including both solid and true CSG properties, Second Moments of Area (indicative of rigidity) and Section Moduli (indicative of strength). Comparisons of CSG properties derived from different methods require conversion equations, but a carefully considered decision was made to limit the use of conversion equations and the extent of any data transformation given the already challenging nature of the fragmented and commingled skeletal material analysed here. The rationale for this is discussed throughout this chapter.

6.1.1 Manual behaviour and upper limb biomechanics

The CSG properties of the humerus have been shown to reflect *in vivo* mechanical loading associated with manual activity, although the complexities of upper limb biomechanics present challenges in their interpretation. The upper limb is subject to a broader range of physical activities and mechanical directionality, in that the arms can be used both unilaterally or bilaterally and undergo a wider variety of anatomical movements (i.e. flexion, abduction and rotation). As such, attributing humeral cross-sectional geometry to specific activities is difficult (Weiss, 2003), and where studies have offered specific explanations for observed patterns of activity related change in the human skeleton they have risked over-interpreting results. However, experimental (Haapasalo *et al.*, 1996; Sabick, 2004; Shaw and Stock, 2009a) and bioanthropological (Churchill *et al*., 1997; Stock and Pfeiffer, 2004; Rhodes and Knüsel, 2005; Auerbach and Ruff, 2006; Marchi *et al.*, 2006; Sparacello *et al.*, 2011; Macintosh *et al.*, 2014a; Sparacello *et al*., 2015) research, as well as studies combining these approaches (Macintosh *et al.,* 2017; Ruff *et al.*, 1993; Schmitt *et al*., 2003; Shaw, 2011), have shown that the biomechanical properties of the upper limb are reflective of manipulative behaviours and can be useful for exploring broad patterns of physical activity in past populations at the group level. Whilst the variety of anatomical movements associated with manual activity makes the biomechanics of the upper limbs complex (Pennestrì *et al.*, 2007), mechanical loading of the upper limb has been suggested to have greater influence on the humerus than the forearm (Kontulainen *et al.*, 2002; Nadell and Shaw, 2016; Shaw and Stock, 2009a). Similarly, lateralisation has been shown to occur more in the humerus than the ulna and radius (Auerbach and Ruff, 2006).

Examining asymmetry in osteometric dimensions and CSG properties between left and right humeri from the same individual can also provide insights into patterns of activity-related mechanical loading and lateralised physical activity (Auerbach and Ruff, 2006; Macintosh *et al.*, 2014a; Ruff, 2019; Sladék *et al.*, 2018; Sparacello *et al.*, 2017c). The upper limb has the potential to exhibit lateralisation, unlike in the lower limb where the mechanical influence of locomotion impacts on the left and right side to equal effect (Shaw, 2011). Humeral asymmetry is also independent of non-activity related factors affecting diaphyseal morphology, such as genetics and hormones (Macintosh *et al.*, 2014a; Ruff, 2019). This is particularly important for comparisons between men and women, as differences in norms of reaction to mechanical loading influence sexual dimorphism in diaphyseal morphology (for review see Macintosh *et al.*, 2017, 2018). Thus, analysis of asymmetry enables comparisons between the sexes to be made. Asymmetry, or lateralisation, in the humerus can be explored by calculating percentages of humeral directional asymmetry (%DA) (Steele and Mays, 1995), which compares an individual's left and right CSG properties, or absolute asymmetry (%AA), which compares the maximum and minimum CSG properties, providing an indication of the magnitude of lateralisation irrespective of side (Auerbach and Ruff, 2006) (Table 6.1). %DA is expressed as a percentage of asymmetry within an individual, with positive values representing right bias and negative values left bias (Mays *et al.*, 2002; Stock *et al.*, 2013). In an attempt to establish a threshold for directional asymmetry, Auerbach and Ruff (2006) showed results did not differ when 0%, 0.05% or 1% was used as a cut-off point to measure asymmetry. Shaw (2011) also demonstrated that %DA values for the upper limb accurately reflected reported handedness in modern athletes, confirming that side bias in CSG properties was a reliable indicator of arm dominance.

Table 6.1: Formulae used to calculate asymmetry in the humerus.

Formula	Reference
%DA = (Right- Left)/((Left+ Right)/2) *100	(Steele, 1995)
%AA = (Max- Min)/((Max+ Min)/2) *100	(Auerbach and Ruff, 2006)

A number of studies have explored humeral asymmetry in archaeological populations (Cameron and Pfeiffer, 2014; Macintosh *et al.*, 2014a; Marchi *et al.*, 2006; Rhodes and Knüsel, 2005; Sladék *et al.*, 2016, 2018; Sparacello *et al.*, 2011, 2017; Stock and Pfeiffer, 2004; Villotte *et al.*, 2017) paleoanthropological samples (Kubicka *et al.*, 2018; Shaw *et al.*, 2012), non-human primates (Barros and Soligo, 2013; Stock *et al.*, 2013) and modern athletes (Haapasalo *et al.*, 1996; Shaw, 2011; Shaw and Stock, 2009a). Studies of humeral asymmetry often exclusively examine *TA* and *J*, but asymmetry in cross-section shape has also been used to explore patterns of activity in past populations (Kubicka *et al.*, 2018; Rhodes and Knüsel, 2005). Asymmetry in cross-section shape between left and right humeri indicates that one side exhibits a more elliptical shape whilst the other exhibits greater circularity, and indicates that an individual undertook a diverse range of manual activities that involved lateralised directionality (Rhodes and Knüsel, 2005). Whilst analysis of asymmetry in cross-section shape identifies a difference between the left and right sides, it does not establish which side exhibits the rounder cross-sectional shape and therefore more so reflects a magnitude of asymmetry.

Sládek *et al.* (2016, 2018) analysed long-term trends in humeral asymmetry across continental Europe in order to chart the impact of subsistence change on regimes of physical activity, and documented pronounced changes in asymmetry following the shift from bimanual saddle querns to uni-manual rotary querns. The results of their study also indicated that patterns of humeral asymmetry reflect the emergence of gender specific tasks following the transition to agriculture. As part of the same programme of research, Holt *et al*. (2018b) combined CSG data from France and Italy, thus enabling exploration of long-term trends in post-cranial robusticity across the full latitudinal range of continental Europe. Increased sexual dimorphism in patterns of humeral loading has also been documented following intensification of agriculture in North America (Bridges *et al*., 2000; Wescott and Cunningham, 2006). Specific to southern Europe, a study by Sparacello *et al*. (2011) using the N. Italian Neolithic sample and a central Italian Iron Age group documented increased sexual dimorphism in the Iron Age compared with the Neolithic. The results of their study were interpreted as reflecting a marked sexual division of labour and the development of gendered society in later prehistory, supporting Robb's (1994b, 1994c) models (see Chapter One, Table 1.1; Chapter Two, Section 2.4). This research was later expanded upon by combining analysis of bilateral asymmetry with funerary assemblages (Sparacello *et al*., 2015), demonstrating the effectiveness of using cross-sectional geometry of the humerus to investigate social change in prehistory. Conversely, Macintosh *et al.*'s (2014a) study of Neolithic, Bronze Age and Iron Age groups in central-southern Europe showed that a major divergence in manual habitual behaviours occurred in the Bronze Age, but that sexual dimorphism decreased during the Iron Age, suggesting that the timing of such changes within Europe varied by region, thus underscoring the need to undertake focused regional studies.

6.1.2 Research question two

Exploring differences in CSG properties in the humerus between and within time periods should therefore inform on long-term changes in manual behaviours over the course of the Holocene in the central Mediterranean. On the basis of previous studies exploring upper limb CSG properties in prehistoric Europe (Macintosh *et al.*, 2014a; Marchi *et al.*, 2006; Sládek *et al.*, 2016, 2018; Sparacello *et al.*, 2011) and the models that have been proposed for skeletal (Robb, 1994c), social (Robb, 1994b; Whitehouse, 2001) and economic (Barker, 1999, 2005) change in central Mediterranean later prehistory, some expectations can be proposed. 1) Increased upper limb loading might be expected in the Late Neolithic/Copper Age samples, reflecting an increase in labour intensive food production tasks associated with the intensification of agriculture. 2) With the suggestion that economic diversification and craft specialisation developed in the 4th millennium BC, upper limb properties would be expected to exhibit greater variation and reflect evidence for more diverse physical activities being undertaken from the Copper Age onwards. 3) Increased sexual dimorphism in upper limb CSG properties might be expected from the Copper Age onwards, reflecting the emergence of gender specific roles and establishment of gendered society in the Italian Metal Ages. This chapter explores these social and economic themes through the analysis of Neolithic and Copper Age assemblages from across the Italian peninsula, Sardinia and Malta, and addresses the following research question outlined in Chapter One:

> *Research Question 2) Do patterns of mechanical loading in the upper limb reflect the intensification and diversification of agriculture during the Copper Age? Is there evidence for greater sexual division of labour among Copper Age groups?*

6.2 Materials

The skeletal assemblages used in this study are discussed in detail in Chapter Three and consist of three Neolithic and five Late Neolithic/Copper Age groups from the central Mediterranean. Only humeri from skeletally mature individuals (i.e. with fused epiphyses) and with no indications of major pathology were included in the analysis. In order to investigate changes in humeral CSG properties in males and females between the Neolithic and Copper Age, articulated skeletons with determined biological sex were isolated from the S. Italian Neolithic, N. Italian Neolithic, Copper Age Po Valley and central Italian Copper Age samples. As with the analysis of body size (Chapter Five), additional comparisons with Mesolithic, Bronze Age, Roman, Medieval and Modern period comparative material were made using the Ruff (2018c) European database in order to frame the individual Neolithic and Copper Age samples within a long-term temporal context. The Ruff (2018c) data set consists of CSG properties that account for endosteal (internal) contours, which are not directly comparable with the periosteal or solid CSG properties captured as part of this study, and the justification for their use is provided in the following section (see Section 6.3.1). To explore %DA and %AA, all commingled and fragmented samples were excluded from the analysis. Only individuals from the N. Italian Neolithic and central Italian Copper Age samples were analysed, and compared with data from the Ruff (2018c) data set – again, solid and hollow CSG properties are not directly comparable; however, comparisons of %DA and %AA using CSG derived from both methods has useful heuristic value (see Section 6.3.1).

6.3 Methods: long bone cross-sectional geometric properties

The following section provides a general background to long bone cross-sectional geometry and is intended to serve as a methodological background to both this chapter and the following chapter examining the lower limb (Chapter Seven). Methodological and conceptual details specific to the lower limbs are discussed in Chapter Seven. Long bones have been shown to respond to mechanical strain associated with physical activity, enabling us to understand broad patterns of habitual behaviour in archaeological populations (Ruff, 2019). By modelling long bones as structural beams through the application of beam theory (Huiskes, 1982) and quantifying their cross-sectional properties, it is possible to estimate the intensity and direction of mechanical loading on the human skeleton associated with physical activity. The application of upper and lower limb skeletal biomechanics to archaeological skeletons is an established field of study (Ruff, 2008a, 2018a, 2019) that has provided useful insights into skeletal adaptations to terrain (Lambert *et al.*, 2013; Ruff *et al.*, 2006a), subsistence strategy (Cameron and Pfeiffer, 2014; Marchi *et al.*, 2011; Ruff *et al.*, 2015Sládek *et al.*, 2016; Sparacello and Marchi, 2008; Stock and Pfeiffer, 2004), economy and trade (Pomeroy, 2013) and more recently the effects of chronic disease on post-cranial morphology (Mansukoski and Sparacello, 2018; Sparacello *et al.*, 2016) (for a full overview of studies using lower limb CSG properties see Chapter Seven, Section 7.2).

Table 6.2 provides a summary of the cross-sectional properties analysed in this chapter and their mechanical relevance. For understanding bone response to total compressive and tensile forces, total sub-periosteal cross-sectional area (*TA*) is most useful here, although these mechanical forces are less relevant when attempting to reconstruct habitual behaviour. *TA* can also be considered a broad indicator of overall diaphyseal rigidity and robusticity. For the quantification of bending rigidity in bone, Second Moments of Areas (SMAs), are used. Bending rigidities can be calculated around a bone's anatomical axis, allowing for quantification of the direction of mechanical loading either in the antero-posterior (I_x) or medio-lateral (I_y) planes, or independent from anatomical axes, expressed as maximum (I_{max}) or minimum (I_{min}) bending rigidities. The Polar Second Moment of Area, or *J*, is a measure of torsional and average bending rigidity that is highly correlated with *TA* (Stock and Shaw, 2007). *J* gives an indication of the intensity of mechanical loading and is calculated as the sum of the maximum (I_{max}) and minimum (I_{min}) bending rigidities.

Table 6.2: Cross-sectional geometric properties used in chapter six.

Property	***Definition***	***Mechanical relevance***
TA	Total sub-periosteal cross-sectional area	*Correlate of compressive strength and highly correlated with J*
J	Polar second moments of area	*Sum of* $I_{max} + I_{min}$ *Correlate of torsional and bending rigidity*
I_x/I_y	Cross-sectional shape index	*Calculated by dividing* I_x *by* I_y *Distribution of bone about the anterior-posterior and medio-lateral axes*
I_{max}/I_{min}	Cross-sectional shape index	*Calculated by dividing* I_{max} *by* I_{min}. *Distribution of bone about maximum and minimum axes and indicative of cross-section shape*

Of particular use are shape indices (I_x/I_y and I_{max}/I_{min}), which give an indication of bone cross-sectional shape, and are calculated by dividing perpendicular SMAs. Whilst I_{max}/I_{min} is a general indicator of cross-sectional shape, the I_x/I_y shape index specifies the overall direction of loading in either the antero-posterior (AP) or medio-lateral (ML) plane. Each shape index has greater applicability to different skeletal elements, for example I_x/I_y is less effective in the tibia because of the difficulties of consistently aligning this element to anatomical axes and instead I_{max}/I_{min} offers a better indication of cross-sectional shape (Davies *et al.*, 2012; Stock and Pfeiffer, 2004). In contrast, I_x/I_y is more informative when applied to the humeri and femora since these skeletal elements can be consistently orientated with greater ease, and because their morphology can naturally be extended into both the medio-lateral and antero-posterior planes (i.e. femora and humeri with an elliptical medio-lateral shape can occur, whereas healthy tibiae are more likely to be elliptically shaped in the antero-posterior plane only). I_x/I_y is, however, more susceptible to inter-observer error than I_{max}/I_{min} in that it relies on the practitioner to identify the antero-posterior planes (Stock and Shaw, 2007). In the analysis of CSG properties presented in this chapter, only TA, J and the I_x/I_y and I_{max}/I_{min} shape indices are discussed. The descriptive statistics and box-and-whisker plots for the individual I_x, I_y, I_{max}, I_{min} properties are included in Appendix C.

Within literature on long bone cross-sectional geometry an important terminological distinction is made between bone *strength* and bone *rigidity*. Rigidity relates to resistance of a bone to deformation prior to structural failure and is reflected in *Second Moment of Areas* (SMAs). Strength is related to the ability of the bone to resist breakage and is reflected in

Section Moduli. These associated cross-sectional properties provide an opportunity to explore subtly different bony responses to mechanical loading (Ruff, 2018b, 2019). Much of the literature regarding long bone cross-sectional geometry has used SMAs (Macintosh *et al*., 2014b; Marchi *et al*., 2006; Ruff, 2018c, 2019; Ruff and Hayes, 1983a, 1983b; Sparacello and Marchi, 2008; Stock and Pfeiffer, 2004), although the use of Section Moduli, both in isolation or in combination with SMAs, has gained momentum in recent studies (Ruff, 2008b; Ruff *et al*., 2006a; Sparacello *et al*., 2011, 2017c; Villotte *et al*., 2017). Most recently, Section Moduli have been exclusively used in a major review of post-cranial robusticity in Europe from the Palaeolithic to the present (Ruff, 2018c). This thesis uses an automated method to calculate long bone CSG properties from 3D laser scans developed by Davies *et al.* (2012) which produces SMAs only. Regression equations have been developed to convert SMAs to Section Moduli by raising SMAs to the power of 0.73 (Ruff, 2018b), requiring further processing of CSG data (as with methods to convert solid CSG properties into hollow CSG properties, see Section 6.3.1). Although the inclusion of Section Moduli would be ideal, undertaking the necessary additional steps and conversions requires further transformation of the data and enhances the scope for methodological error. Therefore, the decision was made here to not further transform the raw data any more than was necessary, given the already challenging and fragmented nature of the skeletal material analysed as a part of this study which already required estimations to be made during the data processing stage (see Chapter Four).

It is also important to acknowledge the limitations of the methodology used here, in that the cross-sectional properties defined in Table 6.2 do not fully account for the full complexities and dynamics of mechanical loading on bone tissue (Bertram and Swartz, 1991; Pearson and Lieberman, 2004; Ruff *et al.*, 2006b). Current methods do not examine long bones along their true functional axes (Yoshioka *et al.*, 1987, 1989) and model bone tissue as a fixed material, thus downplaying important factors influencing bone mechanical competence, such as moisture content and related soft tissue structures (Hart *et al.*, 2017). Activity induced bone growth also appears to reflect mechanical loading during adolescence (Haapasalo *et al.*, 1996; Kontulainen *et al.*, 2002; Pearson and Lieberman, 2004). However, long bone CSG properties are still the most objective and conservative means of exploring and quantifying habitual behaviour in past populations, as they do at least relate to *in vivo* adaptations to mechanically induced strain (Ruff, 2008a, 2019; Ruff *et al*., 2006b). As such, CSG properties have clear benefits over more subjective approaches, such as activity related pathology or entheseal change (Wallace *et al.*, 2017). In addition to analysis of cortical bone along long bone diaphyses, recent developments have demonstrated the use of three-dimensional trabecular bone architecture within short bones and long bone epiphyses in reconstructing behaviour (Lorentzon *et al.*, 2005; Saers *et al.*, 2016, 2019; Shaw and Ryan, 2012).

6.3.1 Capturing cross-sectional geometric (CSG) properties

3D laser surface scanning was used to capture the periosteal contours and solid CSG properties of the mid-distal humerus (Davies *et al.*, 2012; see Chapter Four, Figure 4.2). Solid CSG properties of the humerus were captured at the mid-distal (35% of bone length) point of the diaphysis in order to avoid the morphology of the deltoid muscle attachment (Ruff, 2008a, 2019). A variety of methods have been developed to acquire long bone CSG properties, such as direct sectioning (Ruff and Hayes, 1983a), CT scanning (O'Neill and Ruff, 2004), periosteal moulding and bi-planar radiography (Stock, 2002), and most recently 3D laser scanning. 3D scanning is a portable, non-invasive and inexpensive means of rapidly acquiring CSG properties (Davies *et al.*, 2012; Macintosh *et al.*, 2013). Although 3D laser surface scanning only captures external contours, research has demonstrated that periosteal contours alone are highly correlated with true cross-sections and are reliable indicators of mechanical loading, in that they represent the most mechanically relevant bone tissue (Davies *et al.*, 2012; Macintosh *et al.*, 2013; Sparacello and Pearson, 2010; Stock and Shaw, 2007). Solid CSG properties have been used to analyse post-cranial robusticity in a range of archaeological contexts (Macintosh *et al.*, 2014b, 2014a; Mansukoski and Sparacello, 2018) and efficiently examine variation along entire long bone diaphyses (Macintosh *et al.*, 2013; Davies and Stock, 2014). Solid CSG properties do have some limitations, in that by not accounting for the endosteal contours (the internal medullary cavity) they cannot be used to explore the effects of age and nutrition on cortical thickness, and errors when analysing single individuals, such as paleoanthropological samples, can be much larger (Ruff, 2019; Ruff and Larsen, 2014). The 3D scanning approach does, however, have considerable benefits when working with fragmented skeletal material by facilitating the use of methods in 3D digital reconstruction and superimposition (see Chapter Four). 3D models of long bones were acquired using a NextEngine 3D laser scanner at the minimum HD setting, although the N. Italian material from Liguria was partly captured using a DAVID SLS-2 structured light scanner. All scan data were processed and aligned to anatomical axes according to standard orientation protocols (Ruff, 2002) in NextEngine 3D Scan Studio and Rapidform XOR. Cross-sectional properties of bones were captured from the 3D models using the automated programme AsciiSection V3.1 developed by Davies *et al.* (2012).

As body mass constitutes a mechanical force, it is also necessary to control for the effect of body size by standardising cross-sectional properties (Ruff, 2000, 2008a, 2019). It has been argued that body mass primarily has an influence on the weight-bearing elements of the lower limb, but somewhat surprisingly it has been shown that upper limb bones scale to body size similarly to the lower limb and should be standardized in the same way (Ruff, 2000; Ruff *et al.*, 1993). In a recent study, Pomeroy *et al.* (2018) also showed that upper and lower limb cross-sectional properties are both correlated with body mass and lean muscle mass. A combination of bone length and estimated body mass, derived from femoral head diameter, bi-iliac breadth or knee breadth (Auerbach and Ruff, 2004; Ruff *et al.*, 1997, 2005, 2012, 2018; Squyres and Ruff, 2015; see Chapter Five for review of body mass estimation methods), is recommended for standardisation of CSG properties (Ruff, 2019). The occurrence of commingling in many of the Neolithic and Copper Age assemblages used in this study presents considerable methodological challenges due to the inability to re-associate isolated humeri with corresponding femora, or other skeletal elements which can provide body mass estimations. In spite of correlations between the upper limb and body mass, equations have not been widely developed to estimate body mass from isolated humeri.

In response to this issue, all CSG properties of the humerus were "size" standardised by powers of bone length following protocol defined by Ruff (2008a, 2019) for isolated and fragmented skeletal elements. The recommended powers of bone length are length^3 for cross-sectional areas (i.e. *TA*) and length$^{5.33}$ for SMAs (i.e. *I, J*) (Ruff *et al.*, 1993). Although inclusion of body mass is desirable for standardisation of *TA*, *I* and *J*, shape indices (I_x/I_y and I_{max}/I_{min}) do not require controlling for body size, as both standardised and unstandardized *I* values will result in the same shape index and are therefore unaffected by standardisation procedures. Likewise, analysis of %DA and %AA relies on unstandardized CSG properties.

In order to investigate long-term trends in upper limb robusticity, the Neolithic and Copper Age CSG data collected as part of this study were compared with published comparative material that was isolated from the Ruff (2018c) European data set for the Mesolithic, Bronze Age, Roman, Medieval and Modern periods (Chapter Three, Section 3.7). The Upper Palaeolithic is included in the analysis of body size and lower limb cross-sectional geometry but was excluded from the analysis of the upper limb due to low sample size. The Ruff (2018c) data set only contains CSG properties that were obtained using the combined periosteal moulding and bi-planar radiography method (Stock, 2002), that achieves a 'hollow' (or 'true') cross-section by capturing both endosteal and periosteal contours and are therefore not directly comparable with the 'solid' periosteal CSG properties collected as part of this study. A number of regression equations have been developed to convert solid CSG properties into true CSGs (Davies *et al.*, 2012; Macintosh *et al.*, 2013; Sparacello and Pearson, 2010;

Sparacello *et al.*, 2011; Stock and Shaw, 2007). However, such steps ultimately require further data transformation, thus maximising the potential for error – particularly so in the case of the already challenging fragmented and commingled data analysed here. As with converting SMAs to Section Moduli, the successive use of regression equations is avoided here for this reason. Instead a conservative approach that compares total sub-periosteal cross-section area (*TA*), which is directly comparable between both methods is adopted (Davies *et al.*, 2012; Macintosh *et al.*, 2013). *TA* has been shown to be strongly correlated with *J* (Stock and Shaw, 2007) and therefore provides a good approximation of overall bone mechanical competence.

Similarly, investigating long-term trends in %DA and %AA in *TA*, *J* and cross-section shape also relies on the use of true CSG data from the Ruff (2018c) European database. Comparison of solid and true CSG data to explore changing patterns in humeral asymmetry over time is justified here, because %DA and %AA can be viewed representing differences between sides that are relative to each individual and will reflect a representative measure of asymmetry irrespective of what method is used. It would be expected that the majority of error would reflect inter-observer error in how CSG properties were measured, which is a reality of working with published comparative material. Comparisons of %DA and %AA using both solid and true CSG values therefore has useful heuristic value and can identify overall trends that can be explored through future research programmes using directly comparable CSG data. In any case, asymmetry in *TA* is analysed, which enables direct comparisons to be made. Again, the use of equations to convert solid CSG properties to true CSG properties is avoided in this study.

6.3.2 Statistical approach

To explore spatial and temporal variation in CSG properties of the humerus between the individual Neolithic and Copper Age samples, one-way Analysis of Variance (ANOVA) (Field, 2013) and Hochberg GT2 *post-hoc* (Hochberg, 1974) tests were undertaken. The Hochberg GT2 *post-hoc* test was chosen because it provides conservative comparisons and is of greater accuracy when comparing unequal sample sizes (Stoline, 1981). Temporal change in upper limb robusticity among males and females between the Neolithic and Copper Age was investigated using independent *t*-tests. In order to frame the Neolithic and Copper Age data collected here within a long-term temporal context, comparisons were made with the Ruff (2018c) European data set using one-way ANOVA tests and Hochberg GT2 pairwise comparisons. As with the body size data, the primary data from the individual Neolithic and Copper Age sites were combined in order to create representative samples for those individual time periods, allowing them to be compared with samples for the Mesolithic, Bronze Age, Roman, Medieval and Modern periods (see Chapter Five, Section 5.4.4). In this analysis, pooled sex comparisons were made to allow for the inclusion of commingled skeletal material. Any time periods or samples that differ significantly from each other are tabulated and summarised following a similar protocol to Stock *et al*. (2011). The threshold for statistical significance was set at <0.05 for all tests and exact *p* values for all tests are included in Appendix C (Tables C.3-C.5).

Non-parametric tests were required for the analysis of directional asymmetry (%DA). Kruskal-Wallis non-parametric ANOVA tests were undertaken (Kruskal and Wallis, 1952; Ostertagová *et al*., 2014) to explore temporal trends in %DA, whilst comparisons of %DA between males and females within individual time periods were achieved using Mann-Whitney *U* tests (Mann and Whitney, 1947). Finally, Chi-squared (X^2) tests were used to establish if the percentage of individuals with right hand bias in both TA and J was statistically significant. Hand bias was established when both an individual's TA and J values indicated the same directional asymmetry (i.e. both TA and J were either above or below %0) in line with protocol used by Macintosh *et al*. (2014) and Ruff and Auerbach (2006). Of the 145 individuals examined for humeral directional asymmetry (%DA), only seven individuals had fluctuating asymmetry where they had conflicting values for side bias in TA and J (one property indicated right-side bias and the other indicated left side bias), similar to Macintosh *et al*. (2014). These individuals were excluded from the chi-square analysis of hand bias within individual time periods. Temporal analysis of absolute asymmetry (%AA) was performed using one-way ANOVA and Hochberg GT2 or Games-Howell *post-hoc* tests. Comparisons of %AA between males and females within time periods was undertaken using independent *t*-tests.

All CSG, %DA and %AA data are visualised in box-and-whisker plots. The whiskers signify the maximum and minimum values, with the exception of any outliers which are plotted as isolated dots, and the box denotes the limits of the first and third quartiles. Outliers in the data were purposefully retained in order to facilitate analysis of the full range of variation. All outliers were checked to ensure that they were not the result of human error during the data capture or processing stages. The percentages of individuals with left- or right-hand bias are visualised as stacked bar charts. All statistical analysis was conducted using SPSS Version 25.

$$\%Difference = \frac{Later\ time\ period\ mean - Earlier\ time\ period\ mean}{Earlier\ time\ period\ mean} * 100$$

Low and unequal sample sizes can have an impact on statistical robusticity; therefore, the analysis of upper limb CSG properties also relies on the descriptive statistics. Mean values provide insights into underlying trends in the data, whilst standard deviations and box-and-whisker plots provide insights into the degree of variation within a sample or time period. Calculating the percent difference (% difference) in average *TA* and *J* between consecutive time periods also provides a useful indicator of the magnitude of change in upper limb rigidity over time. %Difference was calculated using the formula presented below and expresses increases or decreases between consecutive time periods as a percentage. Positive values indicate temporal increase and negative vales indicate temporal decrease.

6.4 Results

The following section presents the results from the analysis of upper limb solid CSG properties, and includes an investigation of temporal trends in total sub-periosteal area (*TA*) at the mid-distal (35%) humerus, spatial variation in mid-distal CSG properties within the Neolithic and Copper Age (*TA, J,* I_{max}/I_{min}, I_x/I_y), and analysis of long-term trends in humeral asymmetry (%DA and %AA) across the Holocene. Although not discussed in the main analysis, the descriptive statistics for mid-distal humeral SMAs (I_{max}, I_{min}, I_x, I_y) are provided in Tables C.1 and C.2 in Appendix C. Box-and-whisker plots displaying SMAs are provided in Figures C.1-C.4 in Appendix C.

6.4.1 Long-term trends in upper limb robusticity

Comparison of *TA* between time periods (pooled sex samples) was made in order to explore long-term temporal trends in humeral robusticity and rigidity. *TA* was chosen as it is a CSG property that is directly comparable between the solid and hollow methods and because it is correlated with *J* (Ruff, 2019; Stock and Shaw, 2007). The results therefore give an approximation of the overall changes in upper limb robusticity and rigidity from the Mesolithic to Modern periods and provide a backdrop to detailed spatio-temporal analysis of the Neolithic and Copper Age samples and long-term changes in humeral directional asymmetry (%DA and %AA). Table 6.3 contains the summary statistics for humeral mid-distal *TA* by time period, and Table 6.4 displays the results of the one-way ANOVA and *post-hoc* comparisons between time periods. Figure 6.1 is a box-and-whisker plot illustrating temporal variation in *TA* from the Mesolithic to Modern period.

Table 6.3: Summary statistics for total cross-section area (TA) of the mid-distal humerus by time period (left and right combined, pooled sex).

Sample	*N*	***TA (35%)***		
		Mean	St.d	% Difference[a]
Mesolithic	19	882.74	118.02	
Neolithic	88	1021.97	159.57	15.77
Copper Age	156	911.96	158.28	-10.76
Bronze Age	64	829.36	134.27	-9.06
Roman	25	929.68	183.72	12.10
Medieval	62	858.77	113.21	-7.63
Modern	58	912.97	152.77	6.31

[a]Positive values indicate percent increase, negative values indicate percent decrease.

The descriptive statistics and results of the one-way ANOVA reveal that humeral rigidity increased by 15.77% across the transition to agriculture, with the Neolithic sample having greater (p<0.05) *TA* than most other time periods (Table 6.4; Table 6.3). Following the Neolithic, there was decrease of 10.76% in mean *TA* in the Copper Age and a further decrease of 9.06% in the Bronze Age. The Roman period also saw a marked increase (12.10%) in *TA* (Table 6.3; Figure 6.1). With the exception of the Neolithic and Roman period, *TA* appears to have been relatively stable across the duration of prehistory and the historic periods. Consideration of the standard deviations and box-and-whisker plots also shows that the level of within-group variation in *TA* was similar across the Neolithic and Copper Age (Figure 6.1).

Table 6.4: Results of one-way ANOVA and post-hoc comparisons of mid distal TA of the humerus by time period (pooled sex)

Sample	***TA (35%)***		
	Sig. *post-hoc* difference[a,b]		
Mesolithic	NEO		
Neolithic	MESO, CA, BA, MED, MOD		
Copper	NEO		
Bronze Age	NEO, MOD		
Roman			
Medieval	NEO		
Modern	NEO, BA		
ANOVA	**d.f.**	**F**	**Sig.**
Time period[a]	6	12.65	<0.001

[a]Alpha = <0.05. [b]Post-hoc tests using Hochberg GT2, exact p values presented in Table C.3 in Appendix C. MESO = Mesolithic, NEO = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

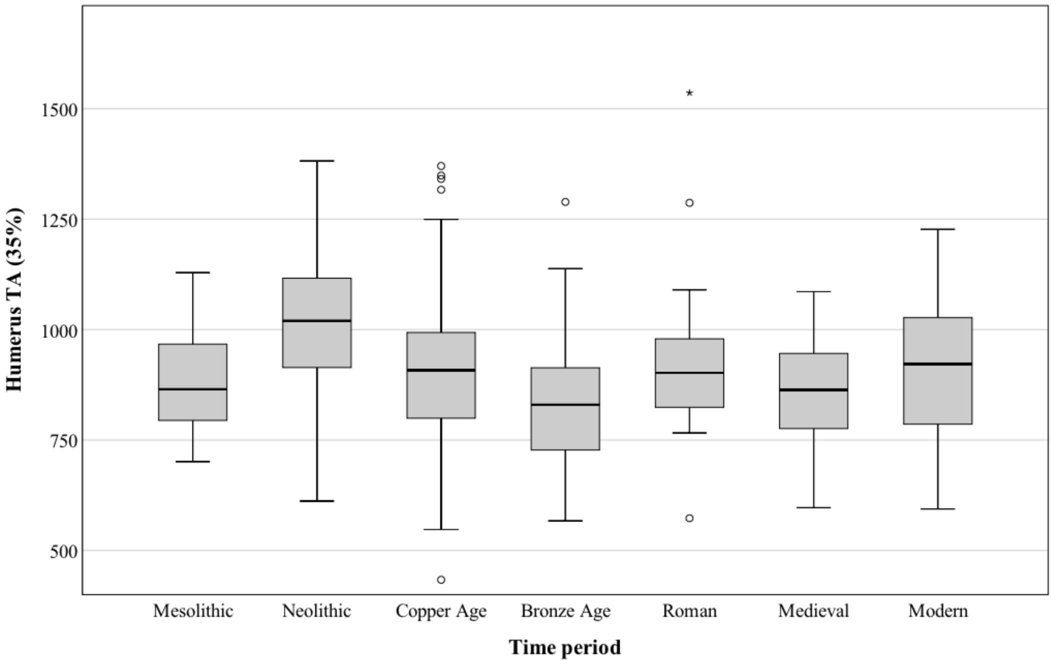


Figure 6.1 – Box-and-whisker plots displaying total sub-periosteal area (TA) of the mid-distal humerus (35%) by time period (pooled sex) within the central Mediterranean, showing general consistency in upper limb rigidity throughout the Holocene, with the exception of a marked increase in the Neolithic period.

6.4.2 Spatio-temporal variation in the Neolithic and Copper Age

Summary statistics for mid-distal solid CSG properties of the humerus for the individual Neolithic and Copper Age sites (pooled sex) are presented in Table 6.5. The results of the one-way ANOVA tests and pairwise comparisons are presented in Table 6.6 and are visualised as box-and-whisker plots in Figures 6.2-6.4. Table 6.7 contains the descriptive statistics and results of the independent sample *t*-tests investigating differences in upper limb CSG properties by sex between the Neolithic and Copper Age. Figure 6.5 displays the box-and-whisker plots depicting variation among males and females between the Neolithic and Copper Age periods.

Table 6.5: Summary statistics for mid-distal (35%) CSG properties of the humerus within the Neolithic and Copper Age samples (left and right combined, pooled sex).

Sample	***N***	**TA**		***J***		I_x/I_y	
		Mean	St.d	Mean	St.d	Mean	St.d
Neolithic N. Italy	54	1058.32	164.93	8226.92	2426.31	1.13	0.15
Neolithic S. Italy	17	929.22	142.53	6397.60	1860.85	1.08	0.12
Neolithic Sardinia	17	999.27	117.83	7331.35	1755.26	1.13	0.21
Copper Age C. Italy	61	917.90	143.93	6335.69	1908.11	1.09	0.16
Copper Age Po Valley	12	830.82	100.32	5141.45	1150.84	1.08	0.12
Late Neolithic Malta	32	808.50	121.70	5114.41	1388.65	1.19	0.13
Copper Age Sardinia	24	957.48	134.50	6814.39	1829.83	1.15	0.18
Alpine Beaker	27	1016.74	184.44	7906.02	2564.16	1.03	0.13

The one-way ANOVA tests revealed significant differences in measures of diaphyseal rigidity in the humerus (*TA* and *J*) between the individual Neolithic and Copper Age samples, although fewer differences in cross-sectional shape (I_x/I_y). Between the Neolithic groups, N. Italians exhibit greater upper limb rigidity than S. Italians and Sardinians, apparent in both *J* and *TA*, although this only reaches significance among the S. Italians (Table 6.6). However, the small and unequal sample sizes mean that these comparisons cannot be considered statistically conclusive, and therefore the descriptive statistics are also important to consider. The N. Italian sample does exhibit greater mean values for *TA* and *J* (Table 6.5) than all other samples and shows considerable variation in *J* (Figure 6.3). However, this is reflective of the overall decrease in *TA* and *J* coming into the Copper Age (see previous Section 6.4.2) – although relative consistency in humeral CSG properties between the Sardinian Neolithic and Copper Age samples suggests this trend may have been subject to regional variation (Figures 6.2-6.4).

Table 6.6: Results of one-way ANOVA and post-hoc comparisons of mid-distal CSG properties of the humerus between the individual Neolithic and Copper Age sites (pooled sex).

Sample	***TA (35%)***			***J (35%)***			***I_x/I_y (35%)***		
	Sig. *post-hoc* difference[a,b]			Sig. *post-hoc* difference[a,b]			Sig. *post-hoc* difference[a,b]		
Neolithic N. Italy	NEOSI, CACI, CAPV, LNM			NEOSI, CACI, CAPV, LNM					
Neolithic S. Italy	NEONI			NEONI					
Neolithic Sardinia	LNM			LNM					
Copper Age C. Italy	NEONI, LNM			NEONI, APB					
Copper Age Po Valley	NEONI, APB			NEONI, APB					
Late Neolithic Malta	NEONI, NEOSA, CACI, CASA, APB			NEONI, NEOSA, APB			APB		
Copper Age Sardinia	LNN								
Alpine Beaker	CAPV, LNM			CACI, CAPV, LNM			LNM		
ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
By sample[a]	7	11.08	<0.001	7	10.12	<0.001	7	3.05	0.004

[a]Alpha = <0.05. [b]*Post-hoc* tests using Hochberg GT2, exact *p* values presented in Table C.4 in Appendix C. NEONI = Neolithic N. Italy, NEOSI = Neolithic S. Italy, NEOSA = Neolithic Sardinia, CACI = Copper Age central Italy, CAPV - Copper Age Po Valley, LNM = Late Neolithic Malta, CAS = Copper Age Sardinia, APB = Alpine Beaker.

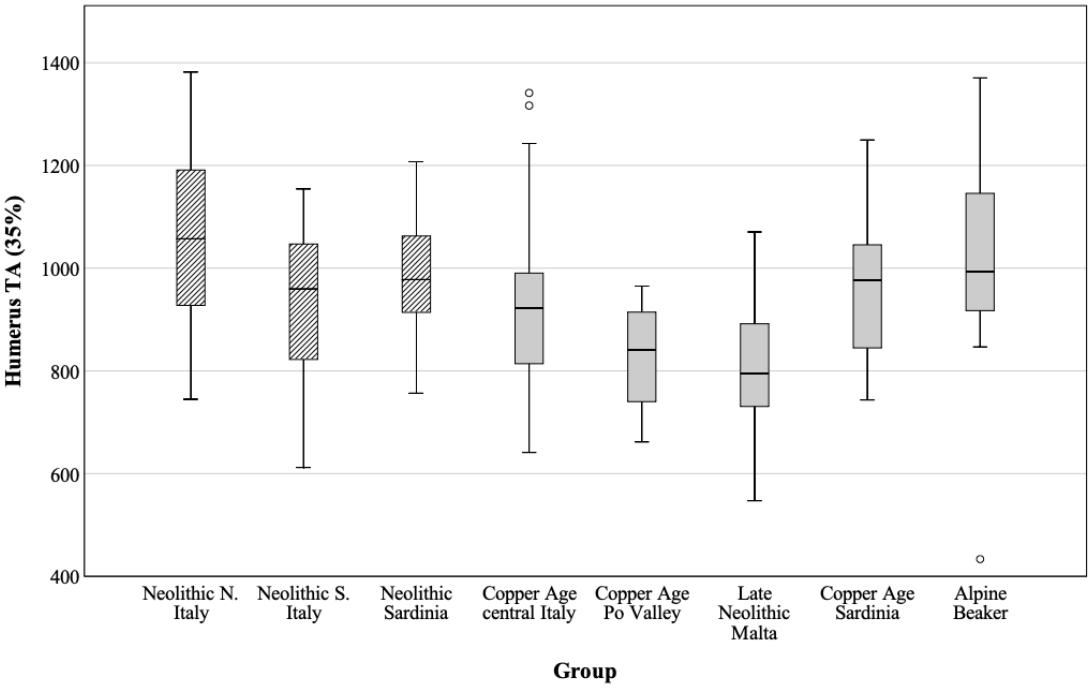


Figure 6.2 – Box-and-whisker plots showing spatial variation in mid-distal (35%) TA in the humerus (35%) between the pooled sex Neolithic and Copper Age/Late Neolithic samples analysed in this study (samples are ordered chronologically, Neolithic groups denoted by shading lines).

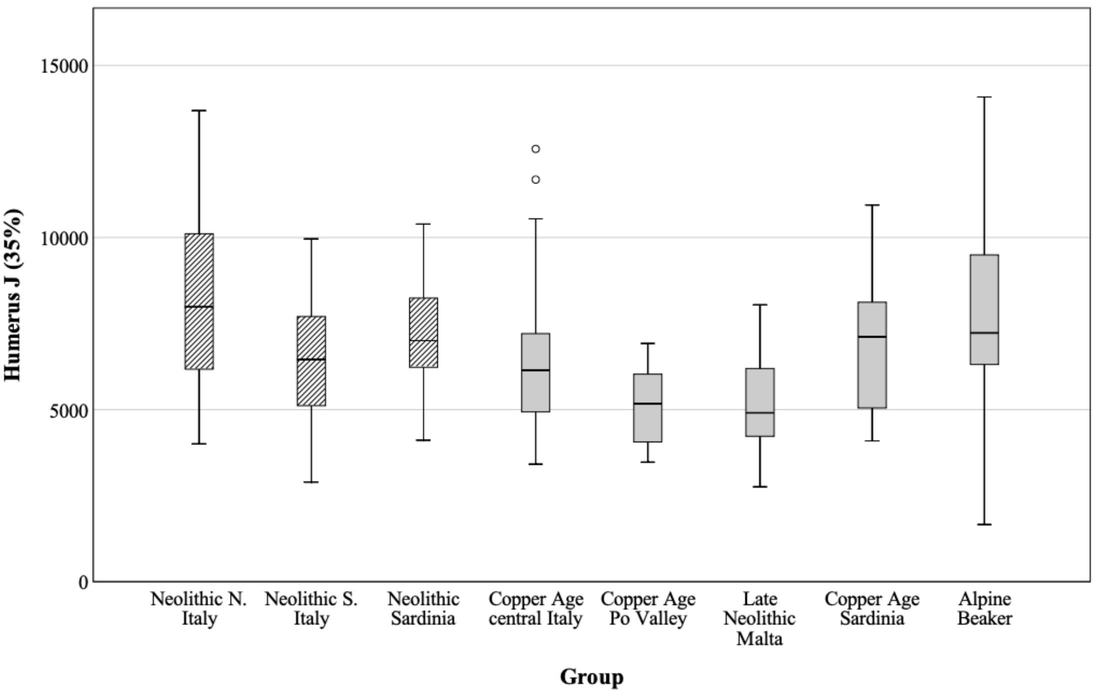


Figure 6.3 – Box-and-whisker plots showing spatial variation in J at the mid-distal (35%) humerus between the pooled sex Neolithic and Copper Age/Late Neolithic samples analysed in this study (samples are ordered chronologically, Neolithic groups denoted by shading lines).

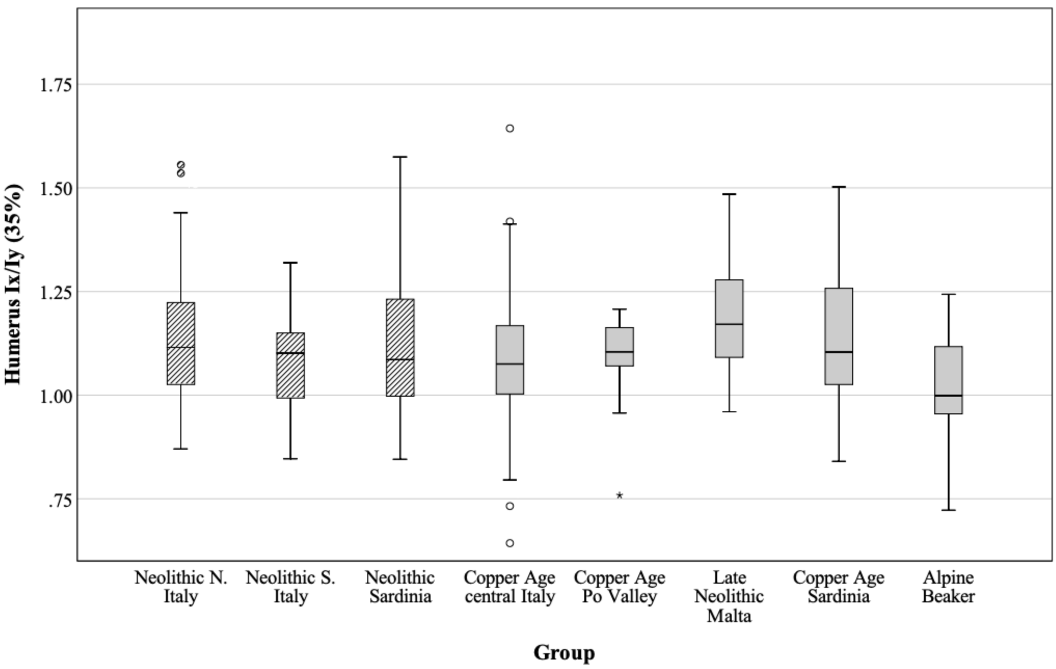


Figure 6.4 – Box-and-whisker plots showing spatial variation in mid-distal cross-sectional shape (I_x/I_y) of the humerus between the pooled sex Neolithic and Copper Age/Late Neolithic samples analysed in this study (samples are ordered chronologically, Neolithic groups denoted by shading lines).

Focused analysis of male and female CSG properties reveals that changes in upper limb robusticity between the Neolithic and Copper Age differed by sex. Males show a significant decrease in all CSG properties of the humerus between the Neolithic and Copper Age (Table 6.7; Figure 6.5). In contrast, females show consistency in humeral morphology, although mean *TA* and *J* values for Copper Age females do show a very slight decrease from the Neolithic, and a small increase in I_x/I_y (Table 6.7). This is perhaps most clearly illustrated by the percentage decrease in *J* coming into the Copper Age, which shows that humeral *J* decreased by 25.87% in males, in strong contrast to an 8.68% decrease in females (Table 6.7). Thus, the magnitude of change in humeral rigidity over time differed by sex.

Table 6.7: Summary statistics and results of the independent t-tests comparing mid-distal CSG properties of the humerus between the Neolithic and Copper Age by sex.

CSG property	**Neolithic**			**Copper Age**			**%**	**Sig. temporal**
	N	Mean	St.d	*N*	Mean	St.d	**Decrease**	**difference**[a]
Males								
TA	45	1085.18	168.05	44	925.39	135.79	14.72	<0.001
J	45	8728.47	2400.23	44	6470.05	1833.66	25.87	<0.001
Ix/Iy	45	1.12	0.14	44	1.06	0.13		0.038
Females								
TA	19	930.42	115.72	26	871.15	146.96	6.37	0.152
J	19	6169.68	1435.42	26	5634.42	1840.60	8.68	0.298
Ix/Iy	19	1.09	0.14	26	1.15	0.17		0.270

[a] Alpha = <0.05

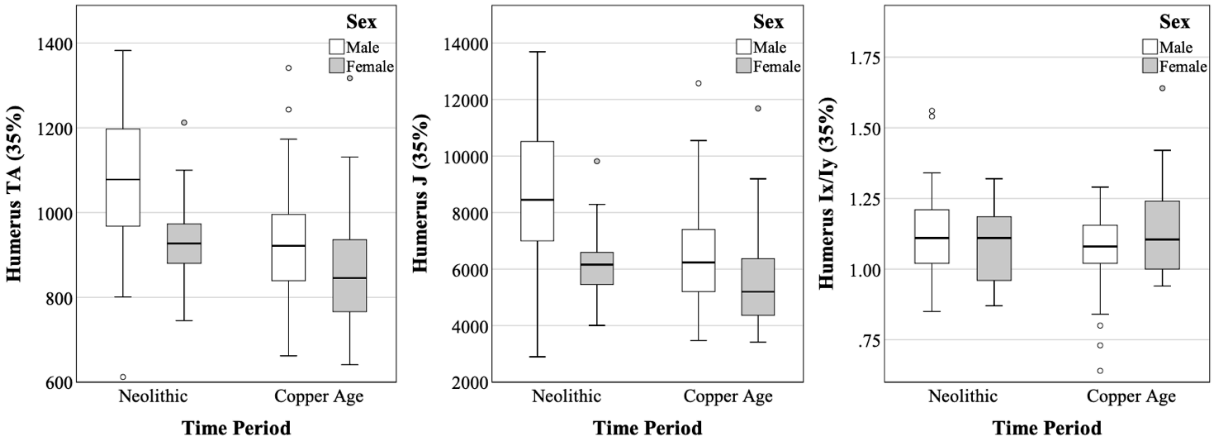


Figure 6.5 – Box-and-whisker plots showing temporal variation in CSG properties of the mid-distal (35%) humerus among males and females between the Neolithic and Copper Age periods (commingled samples removed).

Within the Copper Age, there was relative spatial homogeneity in CSG properties of the humerus, although the Late Neolithic Maltese and Alpine Beaker assemblages stand out as exceptions. The Late Neolithic Maltese have significantly lower mean values for *TA* than the Copper Age central Italian (p=0.021), Sardinian (p=0.006) and Alpine (p <0.001) samples (Figure 6.2, Table 6.5), alongside the lowest mean values for *J* and the greatest mean values for I_x/I_y (Table 6.5; Figures 6.2-6.4). Only in the Copper Age Po Valley group are similarly low levels of humeral rigidity and variability observed, although this could partly be explained by the small size and sex bias (male dominated) of this sample (n=12; Table 6.5). Conversely, the male dominated Alpine Beaker sample exhibits the greatest degree of variation in *J* (Figure 6.3). The Alpine Beaker sample also has markedly higher mean values for *J* than the central Italian (p=0.024), Po Valley (p=0.003) and Maltese (p<0.001) samples. In the analysis of cross-sectional shape, whilst there was limited variation between the Sardinian and Italian Copper Age samples, the Maltese sample has noticeably (p=0.002) more elliptically shaped humeral cross-sections than the Alpine Beakers, who exhibit the lowest I_x/I_y values across all samples (Table 6.5, Table 6.6; Figures 6.2-6.4). In summary, the results reflect the overall decrease in upper robusticity between the Neolithic and Copper Age demonstrated in the analysis of temporal trends in *TA*, but also suggests that this trend was less apparent in the closed island context of Sardinia. There was relative homogeneity among the Copper Age samples, although there was considerable spatial variation between the Maltese and Alpine samples.

6.4.3 *Analysis of Percent Directional Asymmetry (%DA)*

Asymmetry in the humerus was investigated through analysis of directional asymmetry (%DA) in maximum length of the humerus (MXL), correlates of diaphyseal rigidity (unstandardized *TA* and *J*) and cross-sectional shape (I_x/I_y) across time periods and between males and females. Summary statistics for temporal trends in %DA in the humerus are presented in Table 6.8. Box-and-whisker plots visualising temporal differences in %DA are presented in Figures 6.6-6.9. The results of the Kruskal-Wallis tests comparing %DA among males and females over time are displayed in Table 6.9 and the results of the Mann-Whitney *U* tests comparing %DA between males and females within time periods are displayed in Table 6.10. Chi-square (X^2) tests were also undertaken to establish if the percentage of individuals with right-hand bias was significantly different within time periods (Table 6.11), with three sets of tests undertaken on: 1) males only, 2) females only and 3) pooled sex samples. Percentages of individuals with side biased %DA are visualised in stacked bar charts in Figure 6.10.

Table 6.8: Summary statistics for %DA in CSG properties (35%) and maximum length of the humerus by time period and sex.

	N	*MXL*		*TA*		*J*		I_x/I_y	
		Mean	St.D.	Mean	St.D.	Mean	St.D.	Mean	St.D.
Males									
Mesolithic	5	-3.60	-0.90	0.81	4.30	-1.74	12.21	27.20	25.76
Neolithic	16	2.36	0.15	8.20	5.89	15.76	11.46	1.69	7.21
Copper Age	13	1.56	0.11	7.28	13.57	14.04	26.90	9.10	18.83
Bronze Age	16	25.33	1.58	5.34	3.33	10.76	6.92	-6.17	7.44
Roman	5	11.86	2.97	8.51	9.88	15.49	17.38	0.21	6.99
Medieval	11	19.46	1.77	8.47	7.32	20.90	15.77	-11.46	15.24
Modern	17	7.72	0.45	6.25	8.11	11.46	20.09	-4.67	18.76
Females									
Mesolithic	2	0.65	0.45	7.67	0.28	16.18	0.83	-0.44	15.56
Neolithic	6	2.58	1.02	0.51	4.39	1.36	9.09	-0.26	7.32
Copper Age	12	1.51	2.04	4.99	10.80	9.93	21.46	1.87	13.18
Bronze Age	15	1.95	1.26	-0.21	4.95	2.63	10.90	-0.75	10.58
Roman	4	3.13	0.49	10.96	12.63	15.91	19.57	1.49	23.28
Medieval	14	1.11	2.03	6.24	6.03	10.99	17.63	-6.31	18.02
Modern	9	0.81	1.05	3.56	12.29	4.75	21.00	-8.10	13.36

Table 6.9: Results of Kruskal-Wallis tests and post-hoc comparisons investigating %DA in maximum length and CSG properties in the humerus (35%) by time period and sex.

Time period		***MXL*** Sig. *post-hoc* difference[a,b]			***TA*** Sig. *post-hoc* difference[a]			***J*** Sig. *post-hoc* difference[a]			***Ix/Iy*** Sig. *post-hoc* difference[a,b]		
Mesolithic	Male	RO									MED		
	Females												
Neolithic	Male	RO											
	Females												
Copper Age	Male	RO									MED		
	Females												
Bronze Age	Male												
	Females												
Roman	Male	MESO, NEO, CA											
	Females												
Medieval	Male										MESO, CA		
	Females												
Modern	Male												
	Females												
Kruskal-Wallis		**d.f.**	**Test stat.**	**Sig.**	**d.f.**	**Test stat.**	**Sig.**	**d.f.**	**Test stat.**	**Sig.**	**d.f.**	**Test stat.**	**Sig.**
Male		6	24.99	<0.001	6	9.25	0.159	6	10.94	0.090	6	22.35	<0.001
Female		6	10.96	0.900	6	9.48	0.148	6	5.017	0.542	6	3.936	0.685

[a] Alpha = <0.05, [b]Repeated Kruskal-Wallis tests were performed only in cases of significant differences (*MXL* and I_x/I_y among males). Exact p values for *post-hoc* comparison are presented in Table C.5 in Appendix C.
MESO = Mesolithic, NEO = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

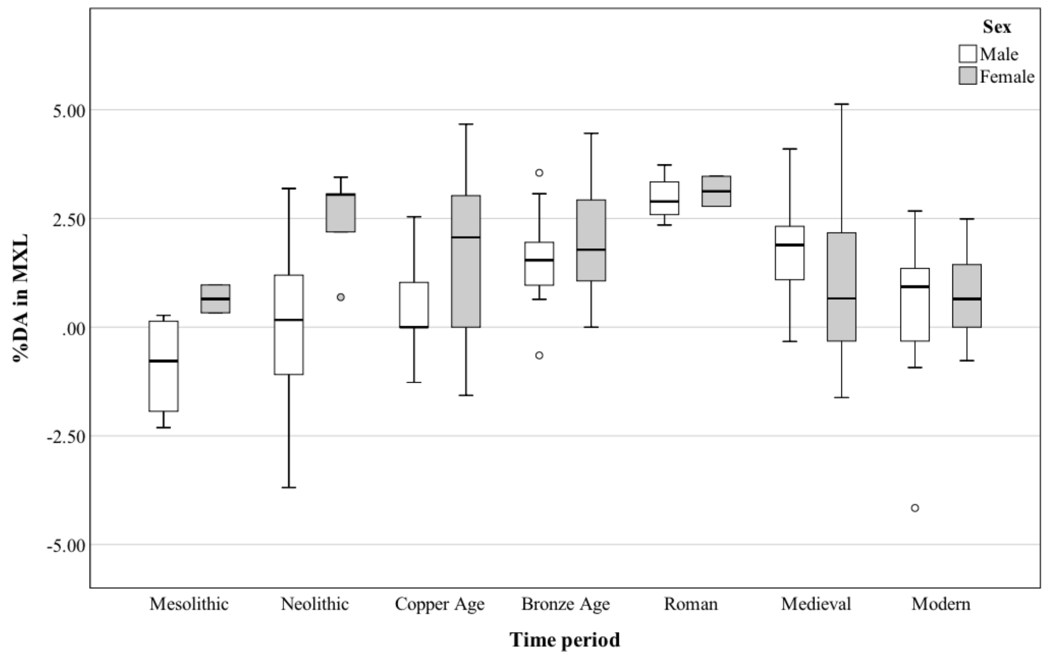


Figure 6.6 – Box-and-whisker plots showing temporal trends in %DA in MXL of the humerus in the central Mediterranean by time period and sex.

The Kruskal-Wallis tests suggest there was limited variation in %DA among females from the Mesolithic to the Modern period (Table 6.9). In males, the Kruskal-Wallis tests highlighted temporal variation in %DA in MXL and cross-section shape, but no significant difference in %DA in *TA* and *J* (Table 6.9). The descriptive statistics do reveal further interesting underlying trends, particularly among males. %DA in MXL is less variable than %DA in CSG properties and females show greater asymmetry in MXL than males in most time periods (Table 6.8; Figure 6.6). Following the transition to agriculture, %DA in *TA* and *J* notably increases among males in the Neolithic and Copper Age but declines slightly in the Bronze Age (Table 6.8; Figures 6.7-6.8). Mean %DA in *TA* and *J* in males then increases again following the Bronze Age in the Roman, Medieval and Modern periods (Figures 6.7-6.8). In females, mean %DA in *TA* and *J* remains consistently low across most time periods (around 0%), as is reflected in the results of the Kruskal-Wallis tests (Table 6.9). There is a slight shift to right biased directional asymmetry in Copper Age females and a notable increase in right biased asymmetry in Roman females. Both males and females in the Copper Age appear to show greater right biased %DA in *TA* and *J* than most other prehistoric time periods and also display considerably more within-group variation in asymmetry (Table 6.8; Figures 6.7-6.8). The summary statistics for I_x/I_y also show that females display consistently lower levels of asymmetry in %DA than males throughout all time periods. In the Mesolithic and Medieval periods, males exhibit extreme asymmetry in cross-section shape (I_x/I_y) (Table 6.9; Figure 6.9.). %DA in I_x/I_y decreases in men between the Mesolithic and Neolithic, with the latter group displaying an average %DA of 1.69%, indicating decreased lateralisation in cross-section shape. Asymmetry in cross-section shape then becomes more prominent again in males during the Copper Age and Bronze Age (Figure 6.9).

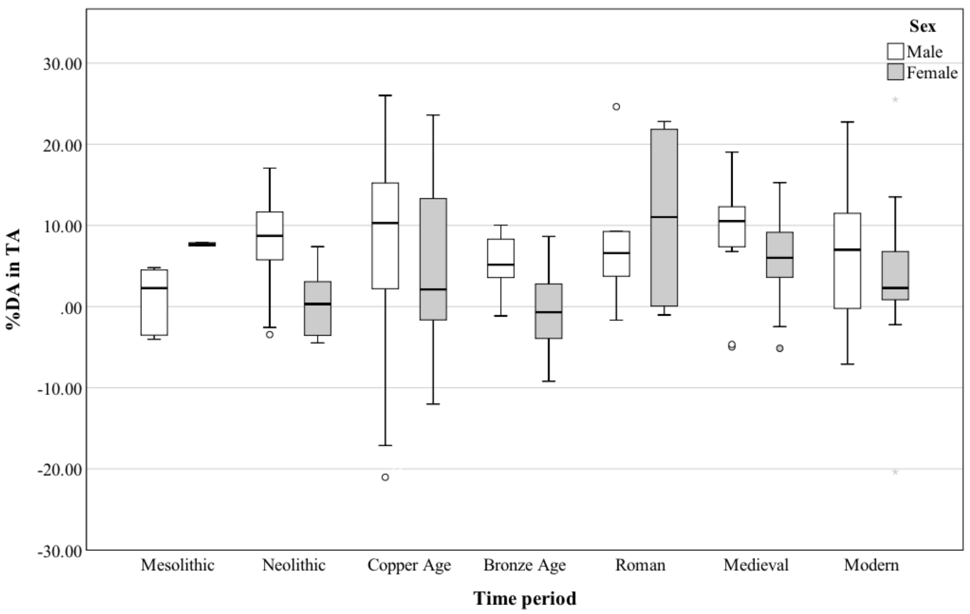


Figure 6.7 – Box-and-whisker plots showing temporal trends in %DA in TA at the mid-distal (35%) humerus in the central Mediterranean by time period and sex.

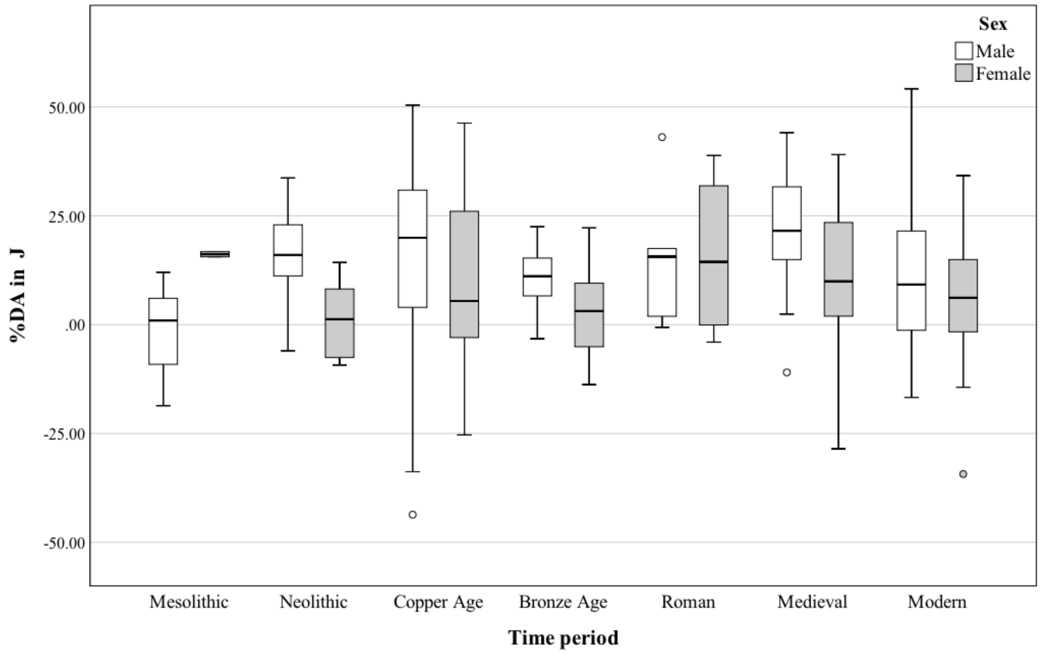


Figure 6.8 – Box-and-whisker plots showing temporal trends in %DA in J of the mid-distal (35%) humerus in the central Mediterranean by time period and sex.

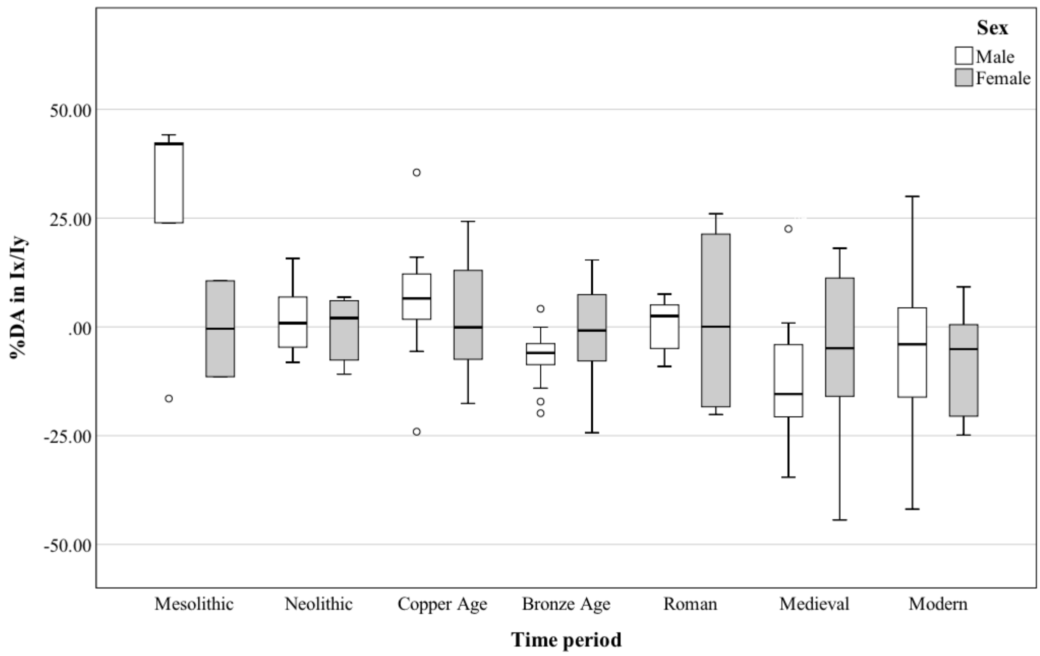


Figure 6.9 – Box-and-whisker plots showing temporal trends in %DA in cross-section shape (I_x/I_y) at the mid-distal (35%) humerus in the central Mediterranean by time period and sex.

Table 6.10: Results of Mann-Whitney U tests comparing %DA in the humerus between males and females within time periods.

Time period	*MXL*	*TA*	*J*	I_x/I_y
	*p**	*p**	*p**	*p**
Mesolithic	0.133	0.095	0.095	0.381
Neolithic	**0.010**	**<u>0.010</u>**	**<u>0.010</u>**	0.747
Copper Age	0.118	0.403	0.462	0.322
Bronze Age	0.599	**<u>0.002</u>**	**<u>0.024</u>**	0.175
Roman	1.000	0.690	0.690	0.690
Medieval	0.277	0.267	0.166	0.291
Modern	0.672	0.597	0.634	0.634

*Alpha = <0.05. Significant values in bold, underlined values indicate greater %DA in males.

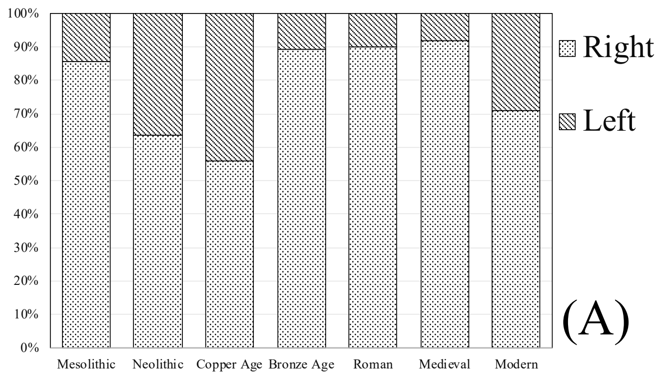
The Mann-Whitney *U* tests comparing %DA between males and females within individual time periods further revealed interesting differences between the sexes. As discussed in the previous section, females show decreased lateralisation and less temporal variation in %DA between time periods, especially for the duration of prehistory. In contrast, males exhibit temporal variability in %DA (Table 6.8). Only in the Neolithic sample do females show significantly greater right biased %DA in MXL than males (Table 6.10; Figure 6.6), but females do generally exhibit more asymmetry in humerus length in all time periods. Whilst males in all time periods exhibit greater average %DA in *TA* and *J*, sexual dimorphism is most pronounced in the Neolithic (*TA* and *J*, p=0.010) and Bronze Age (*TA* p=0.002; *J* p=0.024) (Table 6.10; Figures 6.7-6.8). Interestingly, the significant sexual dimorphism observed in the Neolithic and Bronze Age does not occur in the interim Copper Age period, where no significant difference in %DA between males and females is observed (Table 6.10). Whilst there is a noticeable difference in mean %DA in *TA* and *J* between Copper Age males and females, there is considerable within-group variation and overlap between the sexes at this time, and more so than in any other time period (Table 6.8; Figure 6.6-6.7). The general lack of sexual dimorphism in Copper Age humeral CSG properties is also evidenced by how the decline in upper limb robusticity following the Neolithic only occurred in males, whilst female upper limb robusticity remained more consistent (Section 6.4.2). It is also interesting that the standard deviations show that DA% in I_x/I_y became progressively more variable after prehistory, especially among females (Table 6.8; Figure 6.9), although the Modern sample is an exception to this.

Table 6.11: Side bias by time period and sex and the results of the Chi-Square (X^2) tests investigating whether the percentage of individuals with right bias is significant.

Time period	**Male**				**Chi-Square**	**Female**				**Chi-Square**
	N	*L*	*R*	*R%*	***p****	*N*	*L*	*R*	*R%*	***p****
Mesolithic	5	1	4	80	0.180	2	0	2	100	**N/A**
Neolithic	16	7	9	56.3	0.617	6	1	5	83.3	0.102
Copper Age	14	6	8	57.1	0.593	11	5	6	54.5	0.763
Bronze Age	15	1	14	93.3	**<0.001**	13	2	11	84.6	**0.013**
Roman	5	1	4	80	0.180	4	0	4	100	**N/A**
Medieval	11	1	10	90.9	***0.007***	13	1	12	92.3	**0.002**
Modern	16	4	12	75	**0.046**	8	3	5	62.5	**0.48**

	Pooled sex				**Chi-Square**
	N	*L*	*R*	*R%*	***p****
Mesolithic	7	1	6	85.7	0.059
Neolithic	22	8	14	63.6	0.201
Copper Age	25	11	14	56	0.549
Bronze Age	28	3	25	89.3	**<0.001**
Roman	10	1	9	90	**0.011**
Medieval	24	2	22	91.7	**<0.001**
Modern	24	7	17	70.8	**0.041**

*Alpha = <0.050. Significant values are demarcated by bold italicised font. All significant differences indicate greater percentage of right bias.



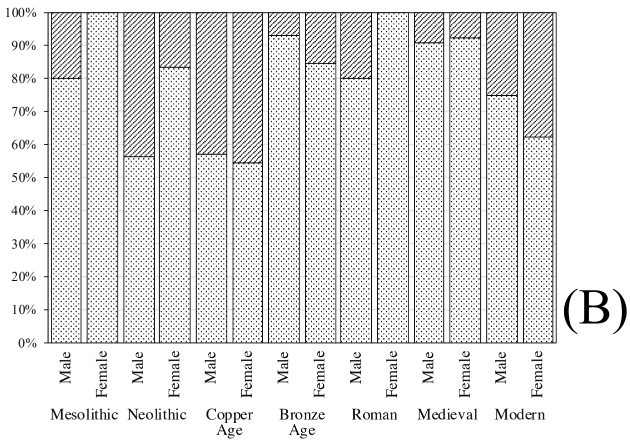


Figure 6.10 - Percentage of individuals with right and left bias in both TA and J: A) pooled sex and by time period, B) by sex and time period.

Finally, the analysis of hand bias by time period and sex demonstrates that the percentage of individuals with right-hand bias is greater in the Bronze Age, Roman, Medieval and Modern samples and ranged from about 85-90% (Table 6.11; Figure 6.10a). The Mesolithic (p = 0.059) sample also contains a high percentage (85.7%) of individuals with right biased %DA (Table 6.11). Significantly greater percentages of right-hand biased men only occurred in the Bronze Age (p = 0.007) and Modern samples (p = 0.046). Among women, high percentages of right biased individuals occurred in the Bronze Age (p = 0.013), Medieval (p = 0.002) and Modern (p = 0.048) periods (Table 6.11). Although Figure 6.10a reports that 100% of Mesolithic and Roman females are right hand biased, it is important to note that both samples are represented by two and five females respectively and are therefore cannot be considered representative (Table 6.11). Notable exceptions are, however, the Neolithic and Copper Age samples, which contain large percentages of individuals with left bias %DA (Table 6.11; Figure 10a). In the Copper Age, both the male and female sub-samples have similarly high percentages of left biased individuals (Males = 42.9%, Females 45.5%), whereas the overall high percentage of left biased individuals of the Neolithic sample (63.6%) is driven by a high number of left biased males (Males = 43.7%, Females 16.7%) (Figure 10b).

6.4.4 Analysis of Percent Absolute Asymmetry (%AA)

Analysis of absolute asymmetry (%AA) was also undertaken to investigate the magnitude of asymmetry in *MXL*, *Ix/Iy* and unstandardized *TA* and *J* between time periods and between males and females within each time period. The descriptive statistics for %AA by sex and time period are presented in Table 6.12, whilst temporal differences in %AA are presented as box-and-whisker plots in Figures 6.11-6.14. The results of the one-way ANOVA and *post-hoc* tests exploring temporal variation in %AA are presented in Table 6.13 and the results of the independent *t*-tests comparing %AA between males and females are presented in Table 6.14.

The ANOVA tests highlighted some temporal differences in asymmetry across the duration of the Holocene. Males show greater temporal variation in *TA*, but limited variation in *J*, I_x/I_y and *MXL*, whilst females show less variation in asymmetry across the Holocene (Table 6.13; Figures 6.11-6.14). Mesolithic males exhibit pronounced %AA in cross-section shape (I_x/I_y), and significantly more than Neolithic (p = 0.008) and Copper Age (p = 0.014) males. Otherwise, %AA in I_x/I_y remains stable among males and females throughout prehistory, until the Roman and Medieval periods, when greater asymmetry is seen (Table 6.12).

Table 6.12: Summary statistics for %AA in CSG properties (35%) and maximum length of the humerus time period and sex.

Time Period	N	MXL* Mean	MXL* St.D.	TA Mean	TA St.D.	J Mean	J St.D.	I_x/I_y Mean	I_x/I_y St.D.
Males									
Mesolithic	5	1.04	1.09	3.83	1.00	9.35	6.60	33.79	12.71
Neolithic	16	1.40	1.19	8.95	4.57	17.18	9.04	6.01	4.07
Copper Age	13	1.01	1.18	12.56	7.33	24.64	14.06	10.66	9.60
Bronze Age	16	1.66	0.88	5.48	3.07	11.16	6.20	8.03	5.21
Roman	5	2.24	1.69	9.18	9.10	15.74	17.10	5.83	2.54
Medieval	11	1.83	1.22	10.22	4.19	22.89	12.35	15.78	10.15
Modern	17	1.20	1.03	8.10	6.12	16.44	16.00	14.63	12.15
Females									
Mesolithic	2	0.65	0.45	7.67	0.28	16.18	0.83	11.01	0.62
Neolithic	6	2.58	1.02	3.34	2.48	7.17	4.82	5.90	3.44
Copper Age	12	1.99	1.52	8.33	8.25	16.74	16.20	10.36	7.77
Bronze Age	15	1.95	1.26	3.99	2.73	9.06	6.19	8.64	5.71
Roman	4	1.80	1.61	11.47	12.00	17.93	17.09	19.85	4.44
Medieval	14	1.75	1.54	7.32	4.52	16.25	12.51	14.56	11.81
Modern	9	0.98	0.87	8.59	9.08	15.93	13.45	12.23	9.18

Table 6.13: Results of ANOVA and post-hoc comparisons investigating %AA in maximum length and CSG properties of the humerus (35%) by time period and sex.

Time period		***MXL*** Sig. *post-hoc* difference[a]	***TA*** Sig. post-hoc difference[a]	***J*** Sig. *post-hoc* difference[a]	I_x/I_y Sig. *post-hoc* difference[a]
Mesolithic	Male		NEO, CA, MED		NEO, RO
	Females		BA	NEO, BA	
Neolithic	Male		MESO		MESO
	Females			MESO	
Copper Age	Male	RO	MESO		
	Females				
Bronze Age	Male				
	Females		MESO	MESO	
Roman	Male	CA			
	Females				
Medieval	Male		MESO		MESO
	Females				
Modern	Male				
	Females				

ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
Male	6	2.257	0.047	6	2.923	0.013	6	2.261	0.046	6	8.019	<0.001
Female	6	1.648	0.153	6	1.388	0.236	6	1.054	0.401	6	1.82	0.112

[a] Alpha = <0.05. *Post-hoc* tests and exact p values are presented in Tables C.6-C.7 in Appendix C.
MESO = Mesolithic, Neo = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

The descriptive statistics also reveal interesting underling trends, which are important to consider in light of the low sizes. Interestingly, mean %AA in *TA* and *J* gradually increases among males from the Mesolithic to Copper Age (Table 6.12; Figures 6.12-6.13). The increase in average %AA in *TA* and *J* is accompanied by a temporal increase in within-group variation, as indicated by the standard deviations (Table 6.12). Mean %AA in *TA* and *J* among males then decreases in the Bronze Age, before increasing again in the Roman and Medieval periods (Table 6.12; Figures 6.12-6.13). In females, mean %AA in *TA* and *J* remains stable throughout prehistory, until elevated asymmetry is observed in the Roman, Medieval and Modern periods. Within the Copper Age, males and females exhibit considerable within-group variation and overlap in %AA across all properties, as demonstrated by the box-and-whisker plots and standard deviations (Table 6.12; Figures 6.11-6.14).

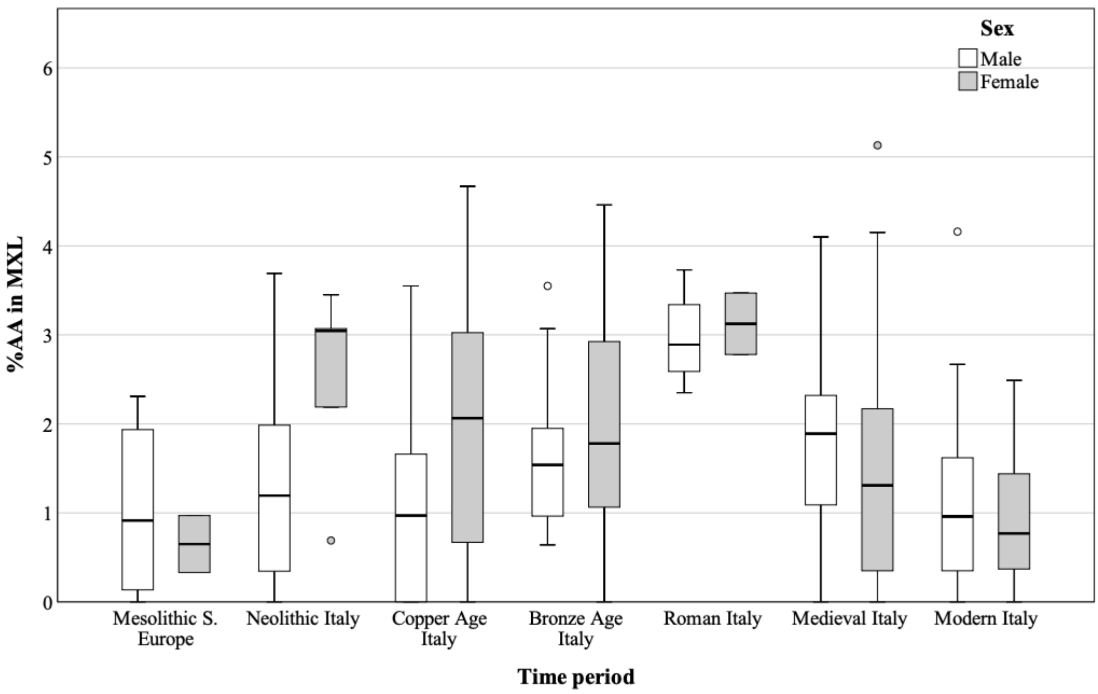


Figure 6.11 – Box-and-whisker plots showing temporal trends in %AA in MXL of the humerus in the central Mediterranean by time period and sex.

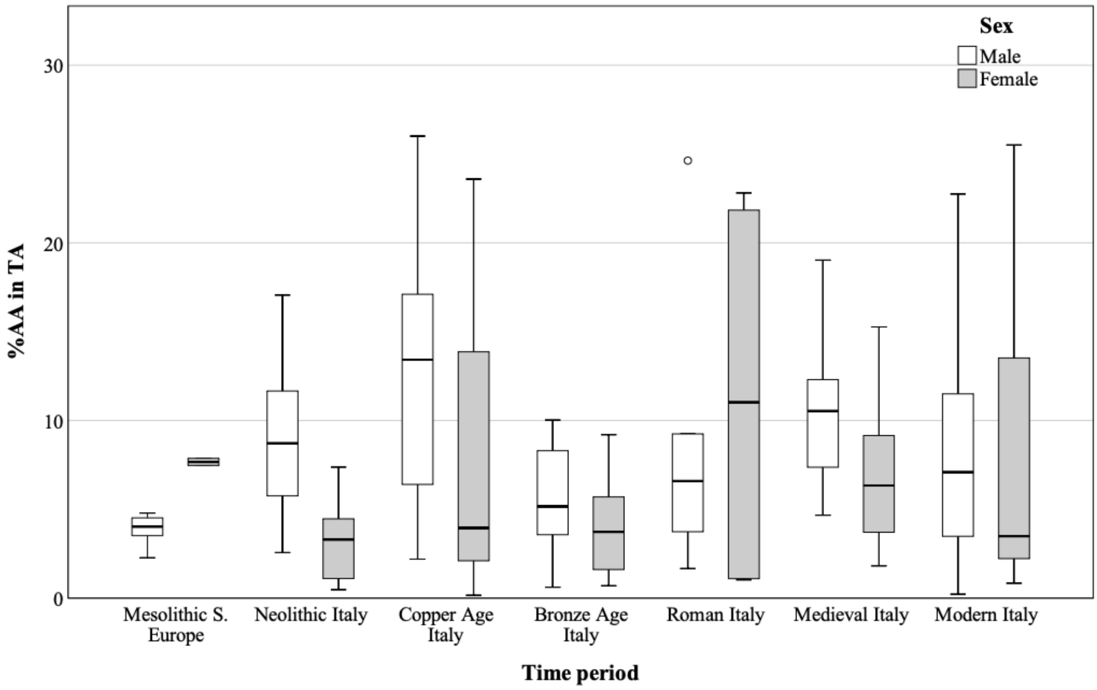


Figure 6.12 – Box-and-whisker plots showing temporal trends in %AA in TA at the mid-distal (35%) humerus in the central Mediterranean by time period and sex.

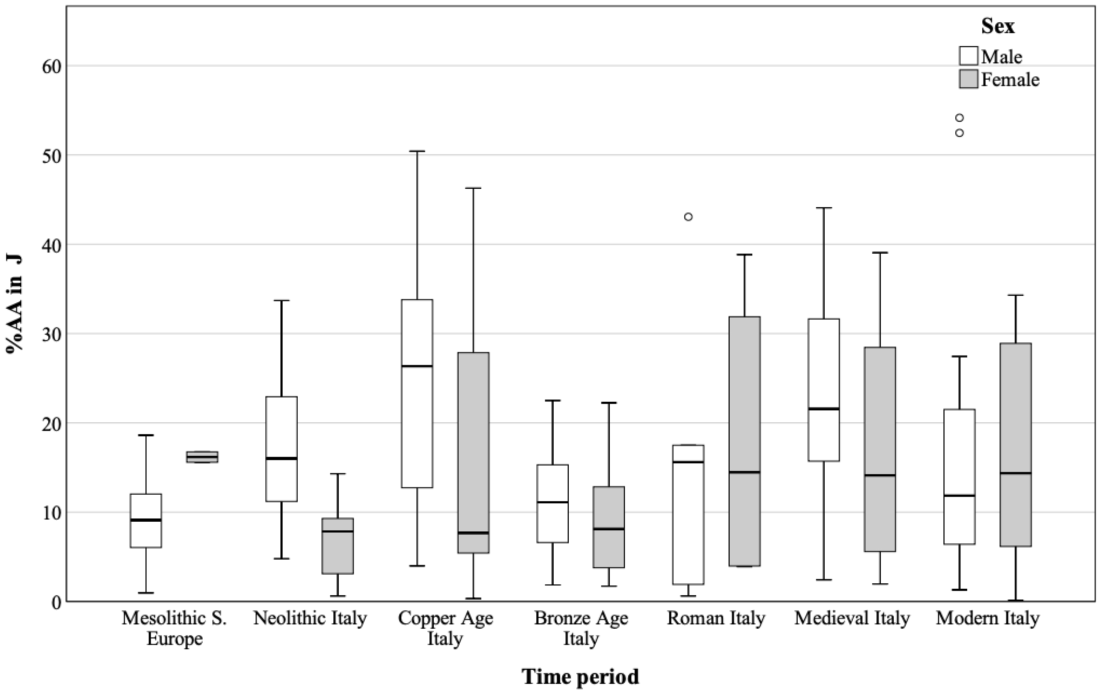


Figure 6.13 – Box-and-whisker plots showing temporal trends in %AA in J of the mid-distal (35%) humerus in the central Mediterranean by time period and sex.

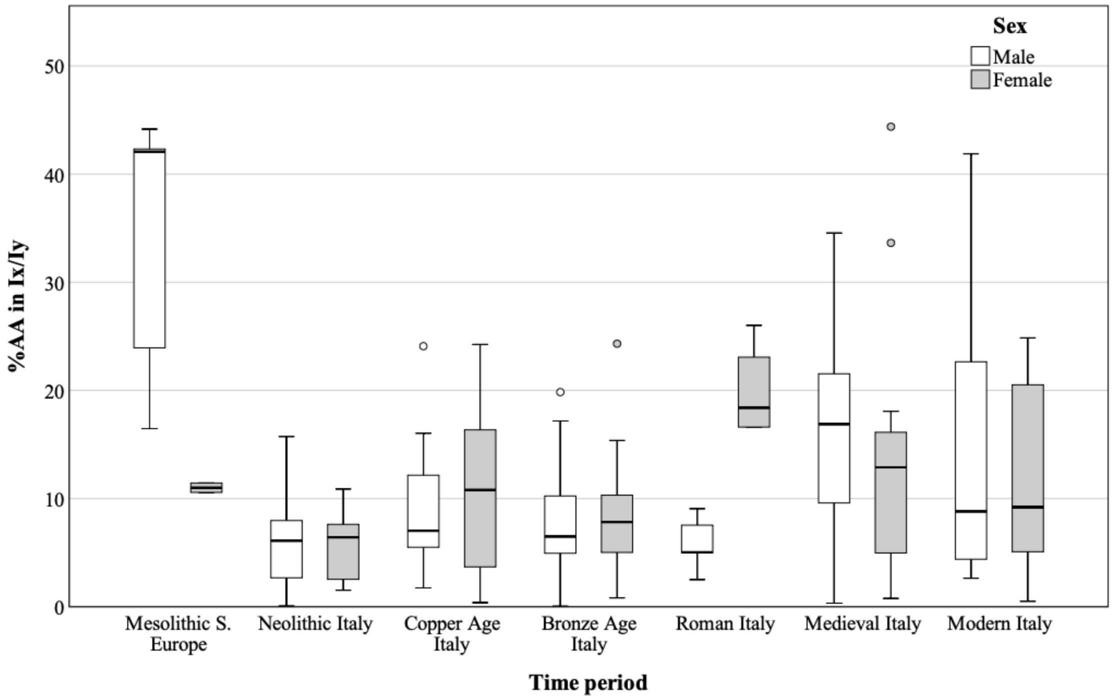


Figure 6.14 – Box-and-whisker plots showing temporal trends in %AA in cross-section shape (I_x/I_y) at the mid-distal (35%) humerus in the central Mediterranean by time period and sex.

The independent *t*-tests exploring sex-based differences in %AA within time periods revealed significant differences between males and females during the Mesolithic and Neolithic (Table 6.14). The results show that Mesolithic females exhibit significantly more %AA in *TA* ($p = 0.004$) than males, but significantly less asymmetry in cross-section shape ($p = 0.016$). In the Neolithic, the results of the analysis of %AA mirrors that of %DA, where females display significantly more asymmetry in *MXL* ($p = 0.045$), but less asymmetry in *TA* ($p = 0.011$) and *J* ($p = 0.019$). Furthermore, the descriptive statistics indicate that females have greater asymmetry in *MXL* during the Copper Age, Bronze Age and Roman periods (Table 6.12; Figure 6.14), similar to the analysis of %DA. Following the Neolithic, there are no major differences in %AA between males and females, with the exception of the Roman period, where females show significantly greater %AA in I_x/I_y (p <0.001). However, the descriptive statistics also show that males display greater %AA in *TA* and *J* throughout the duration of the Holocene (Table 6.12; Figures 6.12-6.13).

Table 6.14: Results of independent t tests comparing %AA in the humerus between males and females within time periods.

Time Period	*MXL*	*TA*	*J*	I_x/I_y
	p=*	*p*=*	*p*=*	*p*=*
Mesolithic	0.670	**0.004**	0.227	**<u>0.016</u>**
Neolithic	**0.045**	**<u>0.011</u>**	**<u>0.019</u>**	0.955
Copper Age	0.082	0.188	0.204	0.933
Bronze Age	0.468	0.167	0.352	0.758
Roman	0.699	0.753	0.854	**0.001**
Medieval	0.893	0.114	0.198	0.788
Modern	0.906	0.424	0.387	0.936

*Alpha = <0.05. Significant values in bold, underlined values indicate greater %AA in males.

6.5 Discussion

This chapter explores social and economic change during the 4th-3rd millennia BC through analysis of upper limb CSG properties and patterns of habitual manual behaviour. It was proposed in Chapter One that overall patterns of manual physical activity would change during the 4th-3rd millennia BC in response to the intensification of agriculture and introduction of diverse economic tasks. Following the social models that have been proposed for later central Mediterranean prehistory (Robb, 1994b; Whitehouse, 2001), it was also hypothesised that increased sexual dimorphism in upper limb CSG properties would be observed in the Copper Age with the emergence of gendered society. Whilst lower limb CSG properties are easier to interpret, understanding humeral CSG properties is more difficult, owing to the complex and highly variable nature of manual activities. In spite of these interpretive problems, the results presented in this chapter have revealed important temporal and spatial trends in upper limb robusticity and manipulative behaviours that can be interpreted within the cultural contexts of the central Mediterranean Neolithic and Copper Age. The results suggest that there was relatively limited spatial variation in manual physical activity in different areas of the central Mediterranean within the Neolithic and Copper Age periods. There was a temporal decline in upper limb robusticity coming into the Copper Age, although this appears to have been part of a larger long-term trend that was more evident in men. The results also revealed a lack of sexual dimorphism in humeral asymmetry during the Copper Age, in strong contrast to the adjacent Neolithic and Bronze Age periods, which challenges the widely accepted social models that have been proposed for the later prehistory of the central Mediterranean.

6.5.1 *Spatial and temporal trends in upper limb robusticity*

The temporal analysis of total sub-periosteal area (*TA*) at the mid-distal humerus enabled direct comparison between the Ruff (2018c) European database and the Neolithic and Copper Age data collected as part of this study and allowed an exploration of long-term trends in upper limb robusticity across the *longue durée* of the Holocene. When considering *TA* as a proxy for diaphyseal rigidity that is highly correlated with *J* (Ruff, 2019; Stock and Shaw, 2007) , the results indicate that upper limb robusticity increased significantly during the transition to agriculture, but declined in the succeeding Copper Age and Bronze Age. Only in the Roman period does upper limb robusticity appear to increase again, before subsequently declining in the Medieval and Modern periods. Increased mechanical loading has been documented in established agricultural societies in Europe (Holt *et al.*, 2018a) and North America (Bridges, 1989; Bridges *et al.*, 2000; but see Larsen, 2015), and the results of this chapter further corroborate the findings of Marchi *et al.*'s (2006) previous study on the N. Italian Ligurian sample. However, long-term trends in upper limb robusticity in the central Mediterranean differ from those reported for wider continental Europe and North Africa, where elevated upper limb robusticity is observed in Mesolithic groups (Holt *et al.*, 2018a; Stock *et al.*, 2011).

Aside from the notable increases during Neolithic and Roman periods, upper limb robusticity remained at a relatively consistent level during the Mesolithic, Copper Age, Bronze Age, Medieval and Modern periods. It is noteworthy that humeral robusticity considerably increased during two periods of profound social and economic change in the central Mediterranean. The first was the introduction of agriculture and food processing (Malone, 2003) and the second was the introduction of urbanism, social and political complexity and the emergence of mass intensive agricultural production (Kron, 2017). The pattern of temporal change in upper limb robusticity mirrors the long-term trends in body size (Chapter Five) and the lower limb (Chapter Seven) which document major changes in stature, body mass and lower limb robusticity during the Neolithic and Roman periods. Similar to wider Europe, the increase in humeral robusticity during the Neolithic likely reflects the introduction of physically demanding food processing tasks (Molleson, 1994), with the subsequent decline in the Metal Ages and historic periods reflecting progressive technological developments and introduction of mechanisation that diminished the need for intensive manual labour (Holt *et al.*, 2018a). This appears to be the case in the central Mediterranean, as upper limb robusticity markedly decreases after the Neolithic during the Copper and Bronze Ages. However, the consistency in humeral CSG properties between the Sardinian Neolithic and Copper Age samples suggests that there was some regional variation in how this trend played out within the central

Mediterranean. The analysis of temporal trends among males and females between the Neolithic and Copper Age also demonstrates that the temporal decline in upper limb robusticity differed between sexes. The drop in upper limb robusticity coming into the Copper Age was much more pronounced in men than women, further exemplifying the overall consistency of female upper limb morphology over the ca. 12,000 years represented in this chapter.

The decline in upper limb robusticity from the Neolithic to Copper Age does, however, suggest that Copper Age groups undertook less physically demanding manual activities. With the suggestion that agriculture intensified in the later Neolithic and Copper Age (Barker, 1999; Cazzella and Guidi, 2011; Cocchi Genick, 2009), an increase in upper limb loading was expected, as observed in Europe in the Middle/Late Neolithic by Holt *et al*. (2018b). However, the results from the upper limb do not support this scenario. The precise nature of agricultural intensification at the end of the central Mediterranean Neolithic has been discussed at length (Barker, 1981, 1999; Robb, 2007), and it has instead been suggested that pastoralism increased and intensified (Robb, 2007). Increased pastoralism would not be reflected in patterns of manual activity, and would instead be expected to manifest in the lower limb as evidence for increased terrestrial mobility (Robb, 1994c) (see Chapter Seven).

Interpreting the CSG properties of the individual commingled and pooled sex Neolithic and Copper Age samples is challenging. The analysis showed that there was relative homogeneity among the Copper Age samples from the Italian peninsula and Sardinia, but highlighted differences between the Maltese Late Neolithic and Alpine Beaker samples. The similarities in the biomechanical profiles of the Italian Copper Age samples suggest that the intensity and range of manual physical activities being undertaken by these coeval groups were relatively similar. The differences between the Late Neolithic Maltese and Bell Beaker samples, which both represent very distinct archaeological contexts, suggest that the diversity of the archaeological record in the central Mediterranean during the 4^{th}-3^{rd} millennia BC is somewhat reflected in upper limb biomechanics and regional differences in manual activity.

The lower TA and J, but higher I_x/I_y, values among the Late Neolithic Maltese sample is also notable. Increased I_x/I_y values in humeri indicate an elliptical cross-section shape in the antero-posterior plane and are usually interpreted as evidence for repetitive unidirectional habitual behaviour (Ruff, 2019; Stock and Pfeiffer, 2004) and food processing among early agricultural societies (Larsen, 2015; Stock *et al.*, 2011). High numbers of querns are known from Late Neolithic Malta (Malone, 2009; Trump, 1966), and it has been suggested that agriculture intensified during the *Tarxien* phase under a more controlled system, of which the megalithic Temples formed a focus (Stoddart *et al.*, 1993; Trump, 1980). Furthermore, the proliferation of stone masonry on the Maltese Islands during the *Tarxien* phase (Trump, 2002) could also be argued as a plausible explanation for the high I_x/I_y values among the Late Neolithic Maltese sample. Experimental studies have shown that such activities would have involved vigorous and repetitive unidirectional manual activity (Larocca, 2016; pers. comm. Caruso, S. 2015), although the decreased humeral rigidity (*TA* and *J*) of the Maltese sample is also important to consider. An alternative interpretation for the patterning in the data may therefore be driven by the gracility of the Maltese sample. Pronounced anterior ridges along the distal humeral diaphysis are an artefact of gracility that may result in a more triangular or elliptical cross-section shape (pers. comm., Sparacello, V. 2017). When viewed alongside the decreased *TA* and *J* values, this suggests that the results for all three CSG properties are likely related and reflect decreased levels of mechanically demanding manual behaviour in Late Neolithic Malta.

The similar variation in *TA* between the Neolithic, Copper Age and Bronze Age groups is also interesting, as increased variability might have been expected as a result of agricultural diversification and craft specialisation in the Metal Ages (Barker, 1999; Blake, 2014; Cazzella and Guidi, 2011), which would have introduced a wider range of manual activities. The focused analysis of CSG properties among males and females between the Neolithic and Copper Age showed that Copper Age females had relatively similar variation in pure CSG properties to Neolithic females, although there is a marked decline in variability in *TA* and *J* among males between the Neolithic and Copper Age. This suggests that the intensity of female manual behaviours was reasonably consistent between the Neolithic and Copper Age, but that behaviours among males changed. The decrease in variation within males between the Neolithic and Copper Age would suggest that manual behaviour among men became less diverse, however, the analysis of humeral asymmetry, which is a much more powerful indicator of manual behaviour (Ruff, 2019), shows that the Copper Age sample actually features considerably more variation in directional asymmetry in *TA* and *J* than all other time periods.

6.5.2 Temporal trends in humeral asymmetry

Interestingly, the overall decline in humeral asymmetry documented for wider continental Europe does not appear to have occurred in the central Mediterranean. Sládek *et al*. (2018) reported that upper limb asymmetry declines from the Palaeolithic and Mesolithic onwards; however, the results presented here show that directional (%DA) and absolute (%AA) asymmetry fluctuated considerably throughout the Holocene, particularly among males. Holt *et al*. (2018a), also reported the same long-term decline in asymmetry after the Late Pleistocene in France and Italy. Right biased directional symmetry in *TA* and *J* became more pronounced in males with the onset of agriculture, and increased again during the Copper Age, before declining slightly in the Bronze Age. This trend is mirrored in the analysis of %AA, where progressive lateralisation in early agricultural males is observed. The Bronze Age and Roman period signal a prolonged period of reduced humeral asymmetry in males, before %DA increased in the Medieval period. Despite some notable dissimilarities between the results of the analysis of %AA and %DA, both measures of humeral asymmetry show that females exhibit greater asymmetry in maximum length of the humerus (*MXL*).

The low %DA and %AA in Mesolithic males, in comparison to Mesolithic females, also strongly contrasts with wider Europe, where preagricultural males more often display increased lateralisation and evidence for unilateral activities (Churchill *et al.*, 1997; Marchi *et al.*, 2006; Sladék *et al.*, 2018), although the Mesolithic comparative sample is admittedly small. Pronounced asymmetry in preagricultural males has most often been associated with repetitive uni-manual activities related to hunting, such as throwing and spear thrusting (Schmitt *et al.*, 2003; Sparacello *et al.*, 2017c), or hide preparation (Shaw *et al.*, 2012). After the Mesolithic, males in all time periods exhibit greater %DA and %AA in *TA* and *J*, signifying that men undertook more unilateral and asymmetric manual activities, similar to prehistoric central-southern Europe (Macintosh *et al*., 2014a) and Iron Age Italy (Sparacello *et al.*, 2011). Holt *et al.*'s (2018b) combined study of France and Italy, which brings together data from such a large geographic area (based on the Ruff (2018c) comparative data analysed here), does not necessarily reflect the cultural and economic processes that are unique to each country. The differences between the long-term trends reported here and those from previous studies of wider continental Europe thus underscore the importance of focused regional studies.

The increased lateralisation among men throughout time is in strong contrast to women, who exhibit consistently low levels of lateralisation and evidence for engaging in bimanual tasks following the introduction of agriculture. It is difficult to attribute these results to specific activity regimes, especially given the highly diverse nature of labour division within agricultural societies (Maman and Tate, 1996). However, the low asymmetry among females documented in the central Mediterranean follows that reported for wider continental Europe (Sládek *et al.*, 2016, 2018) and central-southern Europe (Macintosh *et al.*, 2014a) during prehistory, where decreased lateralisation in women has been interpreted as stemming from laborious use of bimanual saddle querns for grain processing. This is likely the scenario for the data presented here, and querns are found in large quantities in Neolithic settlement sites throughout the central Mediterranean (Morter, 2010; Pessina and Tiné, 2018; Robb, 2007; Rossi, 1983; Trump, 1966), constituting a considerable body of evidence for food processing tasks being performed in domestic environments. Ethnographic studies have demonstrated that food processing tasks in traditional agricultural societies are more often undertaken by women (for review see Robin, 2006; Shoemaker *et al.*, 2017), and experimental research has demonstrated that women in European early agricultural societies displayed increased upper limb robusticity beyond that of modern semi-professional rowers (Macintosh *et al.*, 2017). Macintosh's *et al.*'s (2017) research emphasised the vital role of women in undertaking labour intensive food processing tasks that were the driving force behind early agricultural societies. In contrast, the greater asymmetry among agriculturalist males may be related to agricultural activities beyond the domestic zone, such as the use of adzes and harvesting tools. Sickles and adzes are also found throughout the central Mediterranean in large numbers following the introduction of agriculture (Biagi and Nisbet, 1987; Lunardi, 2009; Lunardi and Starnini, 2013; Mazzucco *et al.*, 2017, 2018; Pessina and Tiné, 2018), and their use would have involved repetitive slashing or digging motions that would likely result in unilateral mechanical loading in the upper limb (Pessina and Tiné, 2018).

Asymmetry in maximum length of the humerus was far less variable than asymmetry in CSG properties; however, females exhibit greater right-biased %DA in maximum length of the humerus throughout all of prehistory. This trend was mirrored in the analysis %AA, which also documented greater asymmetry in length of the humerus among females from the Neolithic to Roman period. This was particularly prominent in the Neolithic, but also very pronounced in the Copper Age and Bronze Age. The greater asymmetry in maximum length among females is a reversal of the pattern of sexual dimorphism observed in CSG properties, which is more often greater in males. These results, and the reversed pattern of sexual dimorphism, conform to other studies of asymmetry in Europe (Sládek *et al.*, 2007, 2018; Macintosh *et al.*, 2014a). The opposing sexual dimorphism in %DA and %AA between length and cross-sectional geometry further suggests that asymmetry in maximum length does not reflect habitual manual behaviour (Auerbach and Ruff, 2006; Sládek *et al.*, 2018; Macintosh *et al.*, 2014a). Whilst long bone length is less plastic, asymmetry in bone length has been suggested to reflect developmental instability, growth disturbance and environmental stress (Albert and Greene, 1999; Lewis, 2017). In this context, the very pronounced asymmetry in humeral length among female early agriculturists in the central Mediterranean is significant in coinciding with a divergence in body size (both stature and body mass) between females and males and an overall delayed recovery in body size among women with the onset of agriculture (see Chapter Five).

The analysis of humeral asymmetry (%DA and %AA) revealed interesting trends that shed further light on the social and economic models that have been proposed for the Copper Age central Mediterranean. The increased variability in %DA in CSG properties in the Copper

Age sample, and among women in subsequent time periods, is noteworthy. Interestingly, the pattern of increased variation among females after prehistory is not reflected in the analysis of %AA. The marked variation in asymmetry in *TA* and *J* in the Copper Age indicates that a wider variety of tasks were being undertaken by both males and females, and may relate to the evidence for economic diversification after the Neolithic (Barker, 1999, 2005; Cocchi Genick, 2009) and the introduction of a wider variety of economic activities, such as the exploitation of secondary products in the 4th and 3rd millennia BC (Cazzella and Guidi, 2011; Sherratt, 1981; but see Marciniak, 2011). When combined with the overall reduction in upper limb robusticity following the Neolithic, the results suggest that agricultural intensification during the Copper Age was characterised by a wider *variety* of manual behaviours, versus an increase in the *intensity* of physical activity. Females then show greater variability in %DA in cross-sectional rigidity (*TA* and *J*) and shape (I_x/I_y) than males from the Bronze Age to the Medieval period, indicating that patterns of manual activity performed by women were more diverse over time. In addition to exhibiting more overall variation than males throughout time, variation in %DA in cross-section shape (I_x/I_y) among females appears to increase progressively from the Bronze Age to the Medieval period. This may also reflect gradual economic diversification and specialized craft production among established agricultural communities from the Copper Age onwards (Barker, 1999; Blake, 2014) that would have introduced a wider range of manual activities.

There is limited evidence for widespread and systematic craft specialism in the central Mediterranean Copper Age (Cazzella and Guidi, 2011; Robb, 2007), with the obvious exception of metal working (Dolfini, 2013, 2014; Giardino, 2009), although metal artefacts at this time seem to have held more of a symbolic role rather than any practical function (Barker, 1981; Cocchi Genick, 2004; but see Dolfini, 2011). The Bronze Age saw the proliferation of metallurgy (Giardino, 2005), which would have involved intensification in mining, smelting and production activities, as well as a marked increase textile production and leather working (Bazzanella, 2012; Gleba, 2014, 2017) among other laborious 'industries'. Whilst these types of craft production are known from the Neolithic and Copper Age in the central Mediterranean (Barker, 1999; Malone, 2003; Pessina and Tiné, 2018), it is the technological developments, refinement of production techniques and overall increase in specialised craftworking in the Bronze Age and thereafter that likely resulted in a wider variety of tasks being performed – and likely more so among women. Ethnographic studies have shown that as agriculture intensifies, with the introduction of ploughs and animal traction, the role of women in undertaking economic tasks declines, in favour for an increased role in domestic tasks, child rearing and craft production (Alesina *et al*., 2013; Ember, 1983; Hansen *et al*., 2015). Whilst many production activities would have been undertaken by men, possibly as a means of reaffirming gender roles (Robb, 1994a), the greater diversity in humeral asymmetry among females over that of males suggests that women likely played a predominant role in the development of increasingly diverse specialised craft activities. The evidence for more diverse manual activities being undertaken by both men and women in the Copper Age changed from the Bronze Age onwards and suggests that a pronounced sexual division of labour only developed in the later Metal Ages.

Further exploration of differences in asymmetry between males and females within individual time periods can lend useful insights into the sexual division of labour in past societies and social change in prehistory (Ogilvie and Hilton, 2011; Macintosh *et al*., 2014a; Sparacello *et al.*, 2011). It was hypothesised by Robb (1994c) that differences in habitual behaviour between males and females might be expected in the Metal Ages following the emergence of specialised gender roles and rigidly defined binary gender ideologies. This hypothesis is in accordance with the widely accepted social models that have been proposed for the later prehistory of the central Mediterranean that suggest that gendered ideologies closely aligned to biological sex likely emerged as early as the Copper Age (Robb, 1994a; Whitehouse, 2001) (see Chapter Two, Section 2.4). Interestingly, the results presented here suggest that patterns of manual activity between males and females were significantly different in the Neolithic and Bronze Age, but not in the interim Copper Age period. Within the Copper Age, the biomechanical profiles of males and females and asymmetry (both %DA and %AA) in CSG properties exhibit considerable overlap, suggesting there was a flexible division of labour between men and women that was not overtly dictated by any ingrained binary gender ideology. The lack of sexual dimorphism in the Copper Age is further exemplified by the high percentage of left biased individuals at this time.

A high percentage of left biased individuals occur in both males (42.9%) and females (45.5%) in the Copper Age sample, which greatly exceeds the 10-25% reported for modern western populations (McManus, 2009; Raymond and Pontier, 2004) and the majority of other time periods. The increased occurrence of left biased individuals in past populations is therefore more likely driven by regimes of habitual manual behaviour, than any sudden onset of neurologically determined handedness (Sladék *et al.*, 2018). The different percentages of left biased individuals within the Neolithic male and female sub-samples further exemplifies this, with 43% of Neolithic males displaying left hand bias compared to %16.7 of females, suggesting an activity related cause. The seven individuals exhibiting very low asymmetry and conflicting values for side bias in *TA* and *J* may represent those who extensively engaged in bimanual tasks or ambidextrous individuals, with ambidextrousness occurring in approximately 1% of modern human populations (Perelle and Ehrman, 1994). These results do not support the suggestion that gender roles first emerged during the Copper Age in the central Mediterranean. The widely accepted social models are problematic in that they have been largely developed using indirect artefactual and mortuary evidence and sought to connect biological sex with gendered material culture in a simple manner. Furthermore, discussions on Copper Age gender ideology are frequently included as a prelude to a larger Bronze Age story, which erroneously conflates the social histories of the two periods which span a total of 3000 years.

Several scholars have highlighted the issues with using funerary and artefactual evidence to investigate social change in central Mediterranean prehistory and the problem with attempting to equate biological sex with artefact types (Barfield, 1986; Dolfini, 2006a; Whitehouse, 2001; for broader discussion see Robb and Harris, 2018). Where relationships between biological sex and gendered artefacts have been made, these interpretations have largely relied on skeletal analysis undertaken prior to the widespread application of standard methods in bioarchaeology, further complicating previous approaches. Copper Age Italy has generally received less focused research than the Neolithic and Bronze Age, with discussions concerning gender ideologies in Copper Age Italy more often included as a footnote to the Bronze Age (Robb, 1994a; Whitehouse, 2001). With a critical review of the material evidence, it becomes clear that male/female gender identities are rarely explicitly expressed in Copper Age contexts.

The artefactual record for the Copper Age central Mediterranean shows variable expression of gender (Figure 6.15). The material evidence from which Copper Age gender ideology has primarily been discussed consists of statue stelae (Barfield, 1998; Harris and Hofmann, 2014; Robb, 2009; Whitehouse, 1992a), rock art (Bevan, 2006; Whitehouse, 1992b), figurative art (Holmes and Whitehouse, 1998) and burials (Barfield, 1986; Dolfini, 2006a, 2006b). It has been suggested that typically male and female symbolism was used to explicitly state, reinforce and strengthen binary gender ideology closely aligned to biological sex (Dolfini, 2004; Robb, 1994a; Whitehouse, 2001). Within this binary gender ideology, weapons primarily represented adult males, whilst females are usually denoted by anatomical features and items of personal adornment (Figure 6.15a-b). However, the material record for Copper Age Italy remains extremely fragmented, particularly with regard to figurative art (Figure 6.15c), and most artefactual evidence lacks secure chronology. In particular, statue stelae and rock-art lack secure chronology and likely date to the later Copper Age and represent regionally specific expressions of gender (Harris and Hoffman, 2014). Regarding burial evidence, the historical narrative has placed an emphasis on prominent male "warrior burials" (Guilaine and Zammit, 2005; Miari, 1994), although recent research has shown that Italian Copper Age burials were in fact extremely variable, and are more often disarticulated or communal burials, thus challenging the traditional discourse (Conti *et al.*, 1997; Dolfini, 2006; Miari, 2014; Silvestrini *et al.*, 2011; Figure 6.15d-e). Furthermore, the evidence that has been used to build these traditional discourses has also begun to be scrutinised and challenged in recent years, such as the classic example of a "warrior" burial from Ponte San Pietro (Figure 6.15e). Therefore, the lack of sexual dimorphism in the Copper Age sample is not that surprising and is reflected in the material culture upon closer inspection.

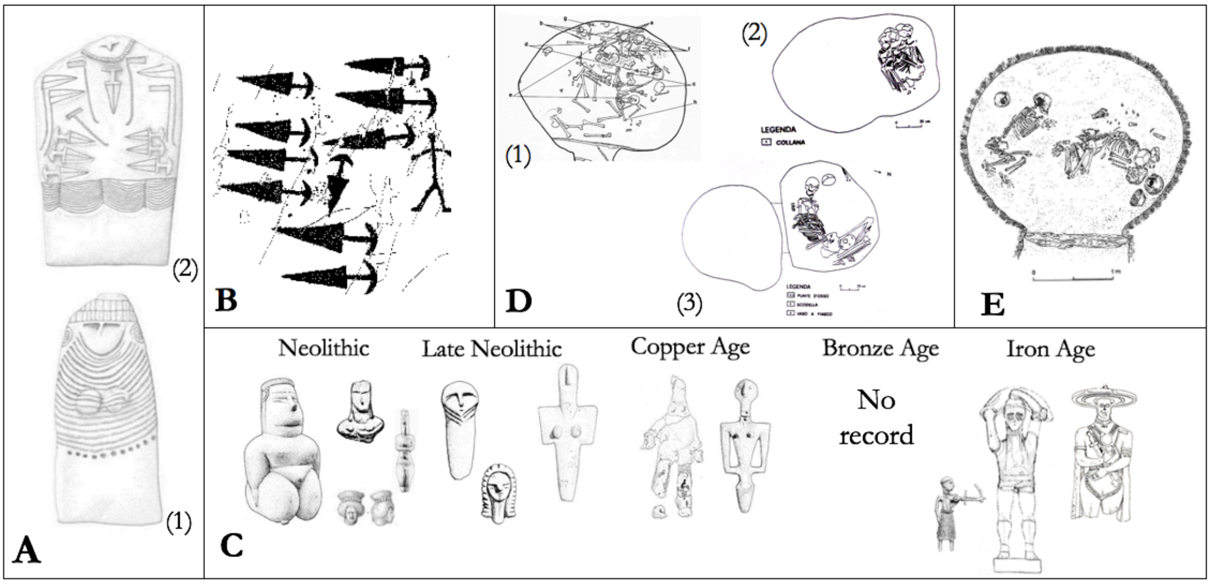


Figure 6.15 – Representative example of the kind of material evidence used to explore gender in Copper Age Italy: A) statue stelae, Lago di Garda, (1) typical female symbolism, (2) typical male symbolism; B) rock art with male gendered symbolism, Cemmo boulder, Val Camonica; C) representative scheme for central Mediterranean figurative art; D) variability of Copper Age mortuary practices documented in recent excavations, (1) ossuary tomb, Tomb 3, Selvicciola, Latium, (2) partially disarticulated primary burial, Tomb 8, Fontenoce-Recanati, Marche, (3) articulated double juvenile burial, Tomb 4, Fontenoce-Recanati, Marche; E) classic example of male "warrior" burial, Tomb of the Widow, Ponte San Pietro, Latium.

In an investigation of social change in Italian prehistory using long bone cross-sectional geometry, Sparacello *et al.* (2011) found evidence for marked sexual division of labour in Iron Age central Italy, which was interpreted as being the result of a rigid Iron Age binary gender ideology that was not only asserted in material culture, but also enacted and reinforced in the day-to-day activities of individuals. The lack of evidence for sexual division of labour in the Copper Age suggests that gender ideologies were weakly developed prior to the Bronze Age in the central Mediterranean, in a pattern similar to central-southern Europe where a divergence in manual behaviours is documented only from the Early Bronze Age onwards (Macintosh *et* *al*., 2014a). Therefore, there is a need to explore and re-investigate these social processes through other lines of direct evidence set within a secure chronological framework, such as bioarchaeology. In a recent review of the current state of gender studies in European prehistory, Robb and Harris (2018) argued that, although distinctions between males and females exist in almost all societies, gender identities were not explicitly or systematically expressed in the Neolithic, in contrast to the later Bronze Age when binary male-female gender identities are consistently seen. As such the "sex/culture dichotomy" that equates biological sex with gendered material culture is not easily applicable to pre-Bronze Age societies. Robb and Harris (2018) also called for less reliance on artefactual and iconographic evidence, and more consideration of bioarchaeological evidence related to everyday life, such as diet, mobility and physical activity. The analysis presented in this chapter has sought to address this issue within the context of the central Mediterranean.

6.6 Conclusion

This chapter investigated the social and economic changes that are associated with the Neolithic and Copper Age central Mediterranean through analysis of cross-sectional geometry of the humerus. As evidenced by the overall increase in upper limb robusticity and changes in humeral asymmetry, the advent of agriculture in the central Mediterranean signalled a profound change in patterns of manual behaviour. Likewise, the Roman period brought with it a second major change in patterns of manual behaviour. As with the analysis of body size (Chapter Five), the analysis here marks out these two periods as times of immensely important social, economic and political change that had a direct impact on the human body. By contrast, the Copper Age marked a point of decreased upper limb robusticity, and the analysis of humeral asymmetry revealed that patterns of manual activity changed as agriculture developed. The evidence for an increasingly wider range of manual activities undertaken from the Copper Age onwards, with the introduction of economic diversification and craft specialisation, also indicates that there was a shift in the division of labour in the Bronze Age as women became increasingly involved in diverse domestic tasks and specialised craft working.

The results show little evidence for the sexual division of labour in the central Mediterranean Copper Age, and strongly contrast with the widely accepted social models that have been proposed for later Italian prehistory, which in the case of the Copper Age have been developed on a very fragmented body of evidence. As opposed to representing any form of strict division of labour, the results instead suggest that there was a flexible division of labour. Prehistoric archaeology has had an overwhelming and disproportionate focus on gender studies (Johnson, 2009), which has likely overshadowed other social changes that may have occurred during the Copper Age. Therefore, there is a genuine need to revisit and review traditional archaeological narratives through the application of new methodologies and archaeological science, as advocated by Robb and Harris (2018). The results presented in this chapter offer an important step towards exploring broad changes in manipulative behaviours in the central Mediterranean, complementing previous studies that laid the framework for this project (Holt *et al*., 2018b; Macintosh *et al*., 2014a; Marchi *et al*., 2006; Sparacello *et al*., 2011), and have set the interpretations within a firm economic and social context. The benefits of a broad time series approach that aids in strengthening the interpretation of patterns in prehistory are also highlighted in the analysis presented here.

7 MOBILITY BEHAVIOUR AND ECONOMIC CHANGE: LOWER LIMB CROSS-SECTIONAL GEOMETRY

7.1 Introduction

Lower limb biomechanics have been widely used to investigate skeletal adaptations to changes in subsistence economy, settlement patterns and levels of terrestrial mobility between past populations, as well as long-term evolutionary changes in lower limb morphology. The lower limb is largely restricted to locomotion, unlike the upper limb which is used for a wider range of manual activities and therefore is susceptible to a greater variation in mechanical loading. The functional constraints of the lower limb thus enable bioarchaeologists to infer patterns of mobility in past populations through the analysis of lower limb cross-sectional geometric properties (henceforth "CSG properties") (Ruff and Larsen, 2014). In studies of lower limb biomechanics, "mobility" is defined as the daily walking and/or running activities of an individual to move from one location to another, and is otherwise referred to in the literature as "terrestrial logistic mobility" (Wescott, 2014). A wealth of experimental and bioarchaeological research has established relationships between specific patterns of mobility and changes in lower limb CSG properties (Macintosh and Stock, 2019; Nadell and Shaw, 2016; Niinimäki *et al.*, 2017; Shaw and Stock, 2009; Stock and Pfeiffer, 2001), aiding in the interpretation of lower limb morphology and mobility behaviours in past populations.

This approach to exploring mobility has been extensively applied to prehistoric and proto-historic populations from across Europe (Holt, 2003; Holt *et al.*, 2018b; Lambert *et al.*, 2013; Macintosh *et al.*, 2014b; Ruff *et al.*, 2015; Sládek *et al.*, 2006b, 2006a), North Africa (Nikita *et al.*, 2011; Stock *et al.*, 2011) and North America (Brock and Ruff, 1988; Larsen, 2015; Ruff and Hayes, 1983a, 1983b; Ruff *et al.*, 1984). Within the central Mediterranean, studies of lower limb CSG properties have been undertaken on Late Upper Palaeolithic, Mesolithic, Neolithic, Bronze Age, Iron Age, Classical and Medieval groups from across the Italian peninsula (Barbieri *et al.*, 2017; Holt, *et al.*, 2018b; Marchi, 2008; Marchi *et al.*, 2006, 2011; Saponetti and Scattarella, 2003; Sparacello *et al.*, 2011, 2018; Ruff *et al.*, 2006a). However, no comprehensive study has been undertaken on human groups from the Copper Age or central Mediterranean islands in spite of the potential to explore the interesting environmental, social and economic factors that are unique to these contexts.

The study of mobility through the application of skeletal biomechanics has developed much over the last three decades. Earlier studies relied on analysis of the femur (Brock and Ruff, 1988; Marchi *et al.*, 2006; Ruff *et al.*, 1984; Sládek *et al.*, 2006a), but the tibia has since been shown to be a greater indicator of mobility behaviour (Stock, 2006). Furthermore, attempting to understand past mobility behaviours by directly comparing CSG properties of males and females is inappropriate due to the norms of reaction of bone tissue to mechanical loading and hormonal differences between sexes that influence long bone robusticity (see Macintosh *et al.*, 2017). Interesting insights can still be achieved by undertaking separate analysis of long-term trends among males and females. It should be reemphasised that the comparisons of humeral asymmetry between males and females presented in the previous chapter were possible because upper limb asymmetry is independent of the hormonal differences between males and females (Macintosh *et al.*, 2014a; Ruff, 2019).

7.1.1 Mobility behaviour and lower limb biomechanics

Lower limb CSG properties offer important insights into mobility behaviours in past populations and can be used to explore the degree of terrestrial mobility in a given group. This approach to reconstructing mobility relies on structural adaptation of the long bones to *in vivo* mechanical loading associated with habitual behaviour and is discussed at length in the previous chapter (see Chapter Six, Section 6.3). Whilst long bone morphology can be influenced by multiple factors (Kini and Nandeesh, 2012), bone tissue has been shown to respond to mechanical loading associated with habitual behaviour through a process termed bone functional adaptation (Ruff *et al.*, 2006b). Bone functional adaptation sees the distribution of new cortical bone tissue in response to mechanical stimuli, which in turn enables estimates of the intensity and direction of mechanical loading to be made. This can be achieved through a biomechanical approach that models the long bones as structural beams and quantifies their cross-sectional properties related to bending rigidity (Huiskes, 1982; Ruff and Hayes, 1983a).

Lower limb CSG properties have been used to investigate skeletal adaptations to terrain (Lambert *et al.*, 2013; Marchi *et al.*, 2006; Parkinson *et al.*, 2018; Ruff, 1999; Ruff *et al.*, 2006a), differences in subsistence strategy (Marchi *et al.*, 2011; Sparacello and Marchi, 2008; Stock and Pfeiffer, 2004), shifts in settlement patterns (Sládek *et al.*, 2006b, 2006a), levels of mobility associated with economy and trade (Pomeroy, 2013), and more recently the potential effects of chronic disease on mobility (Mansukoski and Sparacello, 2018; Sparacello *et al.*, 2016). Long-term studies have also investigated changes in lower limb biomechanics across the Late Pleistocene and Holocene in Europe (Holt, 2003; Holt and Formicola, 2008; Holt, *et al.*, 2018a; Macintosh *et al.*, 2014b; Ruff *et al.*, 2015), North Africa (Stock *et al.*, 2011) and North America (Mummert *et al.*, 2011; Ruff and Hayes, 1983b; Ruff *et al.*, 1984) and have documented a gradual decline in lower limb robusticity, as part of a larger evolutionary trend that is evident in both cortical (Ruff *et al.*, 1993; Shaw and Stock, 2013) and trabecular (Ryan and Shaw, 2015) bone architecture.

Europe presents an almost unparalleled opportunity to explore long-term trends in skeletal change that can be placed within a firm chronological, cultural and economic framework. A number of studies have documented a gradual decline in lower limb robusticity in Europe throughout the duration of the Late Pleistocene and Holocene (see Holt *et al.*, 2018a). In particular, a marked decline in lower limb robusticity has been documented following the transition to agriculture (Macintosh *et al.*, 2014b; Ruff *et al.*, 2015), reflecting the overall reduction in terrestrial mobility as human groups became more sedentary and shifted away from a mobile hunter-gatherer subsistence. In spite of these broader European trends, Neolithic populations in southern Europe have been shown to have robust lower limbs similar to highly terrestrially mobile Late Upper Palaeolithic and Mesolithic populations (Lambert *et al.*, 2013; Marchi *et al.*, 2006, 2011; Ruff *et al.*, 2006a), thus demonstrating the importance of undertaking regional studies.

In contrast to the upper limb, where proximal limb segments (humerus) are most informative on habitual behaviour, research has shown that distal limb segments (tibia) in the lower limb are most reflective of mobility behaviours (Shaw and Stock, 2011; Stock, 2006). Instead, femoral CSG properties have been shown to be strongly influenced by non-activity related factors such as body breadth and pelvic morphology (Davies and Stock, 2014; Ruff, 1995; Ruff *et al.*, 2006a), which can also influence patterns of sexual dimorphism in lower limb biomechanics (Wescott, 2014). As such, femoral CSG properties should consider body breadth whenever possible (Ruff, 2019). Research has also demonstrated the importance of considering the fibula alongside the tibia in studies investigating mobility (Marchi, 2007; Marchi and Borgognini-Tarli, 2004; Marchi and Shaw, 2011; Marchi *et al.*, 2011, 2019; Sparacello *et al.*, 2018b). Unfortunately, analysis of the fibula was not possible in this study because of the high levels of fragmentation and commingling which prevented the tibiofibular complex from being reconstructed.

Although lower limb CSG properties are easier to interpret than upper limb CSG properties, as a result of the functional constraints of locomotion, the definition of mobility has been discussed at length in recent years (see Carlson and Marchi, 2014). Experimental research on modern athletes with known activity regimes has demonstrated how particular mobility behaviours can result in specific forms of skeletal adaptation (Macintosh and Stock, 2019; Niinimäki *et al.*, 2017; Shaw and Stock, 2009, 2013). In a study comparing the tibial CSG properties of field hockey players and long distance runners, where the repetitive forces acting on bone are broadly understood, Shaw and Stock (2009) demonstrated that the unidirectional habitual mobility patterns of long distance runners resulted in anterior-posteriorly (AP) loaded tibiae (elliptical in shape, Figure 7.1a), whereas the multi-directional mobility associated with field hockey resulted in medio-laterally (ML) strengthened tibiae (rounder in shape, Figure 7.1b).

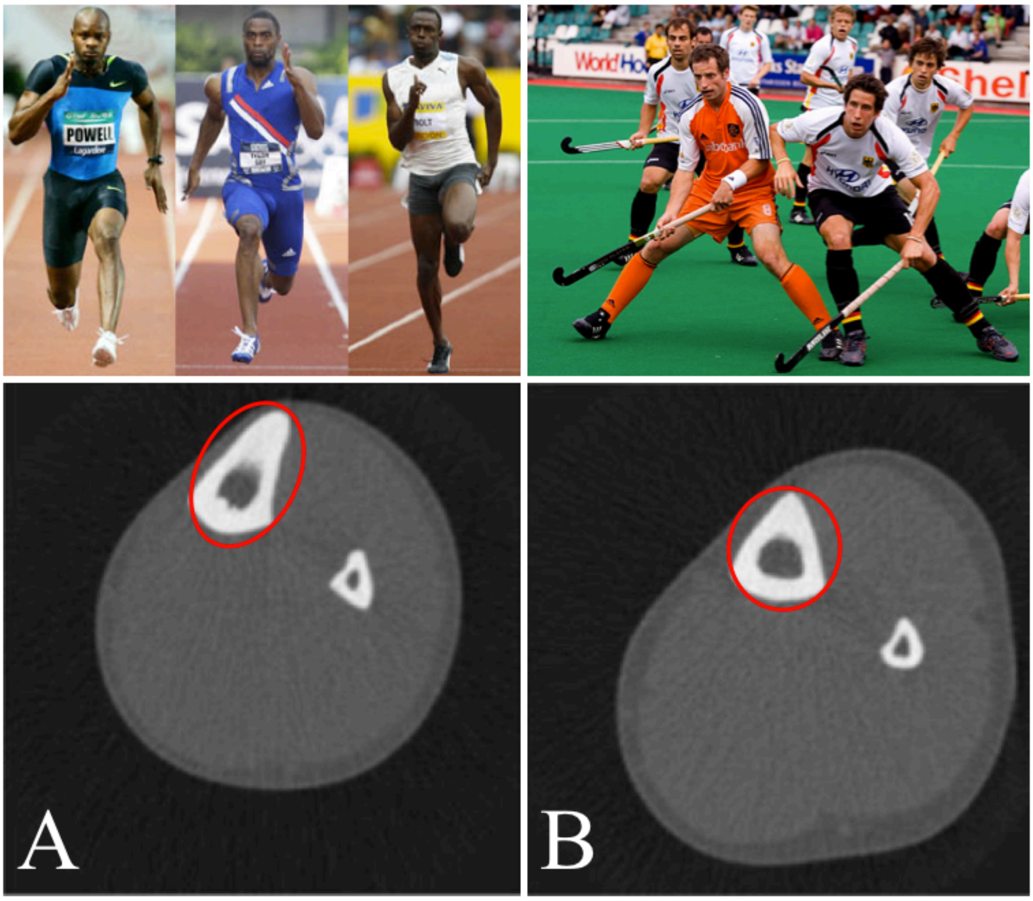


Figure 7.1 – The difference in tibia mid-shaft cross-section shape between A) long distance runners and B) field hockey players. Note that runners have more elliptical antero-posteriorly loaded tibiae associated with unidirectional mobility behaviour, whilst hockey players have rounder tibiae that are medio-laterally strengthened in response to repetitive multi-directional activity (after Shaw and Stock, 2009).

In a classic study of mobility behaviour, Stock and Pfeiffer (2001) compared the upper and lower limb CSG properties of highly terrestrially mobile foragers from Late Stone Age south Africa with Andaman Islanders who relied on marine transport and canoe paddling. The study showed that south African Late Stone Age foragers had increased lower limb rigidity, but decreased upper limb rigidity, in contrast to the Andamanese who displayed greater upper limb rigidity relative to the lower limb, demonstrating a clear relationship between mobility regimes and long bone robusticity. This research has since been further supported by experimental research comparing modern athletes engaging in marine or terrestrial mobility (Macintosh and Stock, 2019; Shaw and Stock, 2013; Weiss, 2003). However, different forms of mobility may produce similar biomechanical signals, particularly in the case of midshaft cross-section shape indices. For example, a rounded mid-shaft cross-section shape can be the result of either a reduction in AP loading, an increase in ML loading, or both processes acting simultaneously (Wescott, 2014). It is therefore important to consider multiple CSG properties when attempting to reconstruct mobility behaviours in past populations.

The impact of topography on lower limb morphology has long been recognised (Holt, *et al.*, 2018a; Marchi *et al.*, 2006; Ruff, 1999; Ruff *et al.*, 2006a). High levels of terrestrial mobility on steep hilly terrain has been shown to lead to increased bending rigidity and anterior-posterior (AP) bending stress (Ruff, 2019; Ruff and Larsen, 2014). However, in a similar process to Shaw and Stock's (2009) hockey player model, medio-lateral (ML) bending stresses can also occur as a result of the multi-directional forces acting on the lower limbs with locomotion on uneven and mountainous land surfaces (Higgins, 2014). Therefore, navigation on uneven and mountainous terrain can also lead to rounder cross-section shape, whereas the unidirectional mobility of hill walking or extremely high levels of mobility on flat terrain result in elliptical and AP loaded cross-section shape (Shaw and Stock, 2009). Holt *et al.* (2018a) comprehensively investigated the effects of terrain on lower limb morphology throughout Europe, using the average hill slope gradients of the geographic areas local to their samples and demonstrated that groups in hilly and mountainous areas displayed increased rigidity and AP bending. It is therefore important to factor in landscape context when attempting to interpret lower limb cross-sectional geometry.

A series of studies using some of the individuals from the N. Italian Neolithic sample analysed here also demonstrated skeletal adaptations to terrain in the lower limb among Neolithic groups in Liguria (Marchi *et al.*, 2006; Sparacello and Marchi, 2008). These previous studies documented high levels of lower limb robusticity and greater bending rigidities, particularly among males, which was attributed to an adaptation to terrestrial mobility on rugged terrain associated with pastoralism (Marchi, 2008; Marchi *et al.*, 2006, 2011; Sparacello and Marchi, 2008). In these studies, comparative analysis showed that the Neolithic Ligurian population displayed levels of lower limb robusticity closer to that of highly terrestrially mobile pre-agricultural groups from the Late Upper Palaeolithic and Mesolithic (Marchi, 2008; Marchi *et al.*, 2011), with similar results seen in Ötzi Tyrolean Iceman (Ruff *et al.*, 2006a) and Neolithic southern France (Lambert *et al.*, 2013). Ruff *et al.* (2006a) demonstrated that the robust lower limbs of the Iceman were adapted to rugged mountainous terrain and suggested he was accustomed to the upland environment in which he was discovered. Within the context of this study, the N. Italian Neolithic sample then represents important reference data against which the degree of lower limb robusticity in other Neolithic and Copper Age samples can be measured.

Robb (1994c) hypothesised that central Mediterranean Copper Age and Bronze Age groups might be expected to display high levels of lower limb robusticity and terrestrial mobility similar to pre-agriculturalist hunter-gatherers given the archaeological evidence for an increase in transhumant pastoralism and population mobility at this time (Table 7.1; see Chapter One, Section 1.2; Table 1.1). Whilst there is evidence for an increase in pastoralism in the Copper Age, the archaeological and palaeodietary evidence is not clear cut and recent research has begun to suggest that this narrative has been overemphasised (see Chapter Two, Section 2.4). In a direct test of Robb's (1994) hypothesis, Marchi *et al*. (2011) compared the Neolithic Ligurian group with a Copper Age sample, reporting a decline in lower limb robusticity after the Neolithic (see also Marchi, 2008). However, Marchi *et al.*'s (2011) analysis relied on available central European Copper Age comparative material, and therefore may not reflect the region specific trends that were proposed by Robb (1994c).

Table 7.1: Robb's (1994c) model of skeletal change through Italian prehistory presented alongside a simplified model of subsistence change (Barker, 1999, 2005; Robb, 2007; Cazzella and Guidi, 2011).

Period	**Mobility levels**	**Subsistence**
Mesolithic	High	Hunting, fishing, gathering
Neolithic	Generally low	Intensive arable agriculture, herding
Copper Age - Bronze Age	Relatively high	Mixed agriculture, increasing pastoralism
Iron Age	Generally low, high for specialised pastoralists	Mixed-agriculture, specialised pastoralists

7.1.2 Research question three

As demonstrated by previous studies, examination of spatial and temporal variation in CSG properties of the lower limb should inform on long-term changes in mobility behaviour over the course of the Late Pleistocene and Holocene in the central Mediterranean. On the basis of models of skeletal, social and economic change that have been proposed for central Mediterranean prehistory (see Chapter One, Table 1) and previous studies exploring lower limb biomechanics in European prehistory, some expected outcomes of the analysis can be proposed. 1) It is expected that a gradual decrease in lower limb robusticity will be observed from the Palaeolithic to the Modern period, but that there will be spatial variation within the Neolithic. As demonstrated by previous studies, the N. Italian Neolithic sample will exhibit robust lower limbs, but it is expected that the S. Italian Neolithic sample might show the reduction in terrestrial mobility that is characteristic of wider Europe following the introduction of agriculture due to regional differences in terrain, settlement and subsistence strategy. 2) Spatial variation in lower limb robusticity is also expected to occur among the Late Neolithic/Copper Age samples, reflecting the diverse physical landscape of the central Mediterranean, which comprises Alpine mountains, coastal plains and small islands. In particular, decreased lower limb robusticity would be expected in the Maltese group, due to their geographically restricted island context, in contrast to the Alpine Beaker sample, who should show adaptation to navigation across rugged mountainous terrain. 3) Using the new CSG data for the Copper Age collected as part of this PhD project, this chapter will also test Robb's (1994c) hypothesis that greater lower limb robusticity might be observed in central Mediterranean Copper Age groups as a result of increased terrestrial mobility associated with pastoralism. These specific points will aid in answering the third research question presented in Chapter One:

> *Research Question 3) Is there evidence for high levels of terrestrial mobility in the Copper Age? Do Neolithic and Copper Age groups exhibit spatial variation in lower limb robusticity?*

7.2 Materials

The skeletal assemblages analysed in this chapter are discussed in depth in Chapter Three and consist of three Neolithic and five Late Neolithic/Copper Age groups from the central Mediterranean. Only femora and tibiae from skeletally mature individuals (i.e. with fused epiphyses) with no indications of major pathology were included in the analysis. Comparisons are made with lower limb CSG data from the Upper Palaeolithic, Mesolithic, Bronze Age, Roman, Medieval and Modern periods (Ruff, 2018) in order to explore long-term trends in lower limb robusticity and mobility, and to provide a broader temporal context to the Neolithic and Copper Age results. The Ruff (2018c) database only contains true CSG properties and therefore cannot be directly compared with the solid CSG properties collected as part of this PhD project. As with the upper limb, the use of regression formulae to convert solid CSG properties into true CSG properties was avoided, and instead only the directly comparable properties of total sub-periosteal area (*TA*) and cross-section shape (I_{max}/I_{min}) were included in the analysis (Chapter Six, Section 6.2.1 for discussion of this). Whilst *TA* is the same irrespective of what method has been used, I_{max}/I_{min} shape indices have been shown to be highly correlated between both CSG methods, and more so than I_x/I_y (Davies *et al.*, 2012). Additionally, shape indices using maximum and minimum SMAs (I_{max}/I_{min}) are more useful in the tibia, given the difficulties in orientating this skeletal element to standard anatomical axes.

Any articulated skeletons from within the Neolithic and Copper Age time periods were also isolated and analysed separate to the commingled skeletal material in order to explore temporal changes in males and females.

7.3 Methods

A full overview of long bone CSG properties was provided in the previous chapter (see Chapter Six, Section 6.2). Methodological details specific to the lower limb are included in the following section.

7.3.1 Lower limb cross-sectional geometry

Solid CSG properties of the lower limb were captured at the mid-shaft (50% of bone length) of the femur and tibia (see Chapter Four, Figure 4.2) using the 3D laser scanning approach described in Chapter Six, Section 6.2. The solid CSG properties analysed in this chapter are displayed in Table 7.2 and defined in Chapter Six, Section 6.2. Previous studies have used anatomical landmarks as standardised cross-sectional locations, such as the location of the nutrient foramen on the diaphysis of the tibia (Ruff, 1987) or the sub-trochanteric region of the femur (Niinimäki *et al*., 2017; Ruff *et al*., 1984). Using anatomical landmarks to establish cross-section location does have a practical use, especially in cases were fragmentation inhibits accurate placement of mid-shaft locations. However, diaphyseal morphology at these section locations is not as reflective of mechanical loading and terrestrial mobility as mid-shaft locations (Stock, 2006). Furthermore, whilst the solid CSG method has been shown to accurately estimate true cross-sectional properties at the mid-diaphysis of the femur and tibia (Sparacello and Pearson, 2010; Stock and Shaw, 2007), estimations of proximal sections are less reliable (Macintosh *et al*., 2013). The use of mid-shaft cross-sections also enables comparisons with a wider body of published literature and comparative data. Long bone length was estimated from fragmented elements using 3D digital reconstruction and superimposition (see Chapter Four, Section 4.3.1).

Table 7.2: Cross-sectional geometric properties used in chapter seven (see Chapter Six, Section 6.3 for a full definition of each property).

Property	***Definition***	***Mechanical relevance***
TA	Total sub-periosteal cross-sectional area	Correlate of compressive strength and highly correlated with J
J	Polar second moments of area	*Sum of* $I_{max} + I_{min}$ Correlate of torsional and bending rigidity
I_{max}/I_{min}	Cross-sectional shape index	*Calculated by dividing* I_{max} *by* I_{min} Distribution of bone about maximum and minimum axes and indicative of cross-section shape

As the lower limb has low levels of asymmetry (Auerbach and Ruff, 2006) only one femur and one tibia from each individual was analysed. Preference was given to the right side when both sides were preserved. Some individuals had only one well preserved femur and one well preserved tibia from opposing sides, as with Ötzi the Iceman (Ruff *et al.*, 2006a). In the commingled assemblages both the left and right sides were analysed so as to increase sample size. However, much care was taken to ensure that contralateral femora and tibiae were not analysed (i.e. the same individual was not analysed twice) using standard methods for the resolution of commingling (see Chapter Four, Section 4.3.3). This was particularly important in the analysis of the Sardinian Copper Age material from Scaba'e Arriu, where it was apparent that contralateral elements were present in the small assemblage. In these cases, the best-preserved side was chosen for analysis.

To standardise CSG properties of the lower limb for the influence of body size, a combination of estimated body mass and bone length was used. Total sub-periosteal area (*TA*) was standardised by dividing by estimated body mass, whilst the polar second moment of area (*J*) was standardised by dividing by bone length^2 x body mass (Ruff, 2008). Body mass estimations were derived from femoral head diameter, and where necessary, knee breadth. Whilst consistent use of one body mass estimation method is ideal, owing to the discrepancies between currently available methods (Lacoste Jeanson *et al.*, 2017; Young *et al.*, 2018; see Chapter Five, Section 5.3), the commingling and fragmentation of the assemblages analysed here presented challenges in this regard. Wherever possible CSG properties were standardised using body mass estimations derived from femoral head diameter, however knee breadth was used for isolated and fragmented femora and tibiae. Body mass estimations using femoral head diameter were derived from regression equations developed for European Holocene populations (Ruff *et al.*, 2012a). Body mass estimations based on knee breadth measurements from the femur and tibia used equations from Squyres and Ruff (2015) and Ruff *et al*. (2018) that were developed on modern north American populations.

7.3.2 Statistical approach

One-way Analysis of Variance (ANOVA) tests were conducted to explore spatial variation in CSG properties of the femur and tibia between the individual Neolithic and Copper Age samples (Field, 2013). *Post-hoc* comparisons were made using Hochberg GT2 tests (Hochberg, 1974), with the exception of comparisons of I_{max}/I_{min} in the femur which used Games-Howell *post-hoc* tests owing to unequal variances between samples (Games and Howell, 1976; Stoline, 1981). The Hochberg GT2 test was chosen as the primary means of pairwise comparison as it is a conservative test that is of most use on samples of unequal size (Stoline, 1981). The results of the one-way ANOVA and *post-hoc* tests are summarised in tables which follow Stock *et al.*'s (2011) reporting protocol. Exact p values for all statistical comparisons are included in Appendix D (Tables D.5-D.11). Temporal variation in TA and I_{max}/I_{min} in the femur and tibia between time periods (pooled sex samples) was investigated using one-way ANOVA tests and pairwise comparisons were made using Hochberg GT2 and Games-Howell tests (Games and Howell, 1976; Hochberg, 1974; Stoline, 1981). Pooled sex analysis was undertaken to enable the inclusion of commingled skeletal material. Separate investigation of temporal trends in males and females was undertaken using one-way ANOVA tests. As with the analysis of the upper limb, Neolithic and Copper Age time period samples were created by pooling the individual sites within these two time periods. Although J values could not be directly compared between all time periods, independent t-tests were used to compare lower limb J values in males and females between the Neolithic and Copper Age. CSG data is visualised in box-and-whisker plots, with the limits of the box denoting the interquartile range and the whiskers signifying the maximum and minimum values. Outliers are plotted as separate points and were retained in the analysis unless it was apparent that they were the result of methodological error during the data collection and processing stages. All statistical analysis was conducted in SPSS Version 25 and the threshold for statistical significance was set as <0.05 for all tests.

In light of the low sample sizes and the likely consequent reduction in statistical robusticity, emphasis is also placed on data exploration and consideration of the descriptive statistics. Mean values provide a strong indication of underlying trends in the data, whilst standard deviations and box-and-whisker plots provide insights into the degree of variation within a sample. To understand the magnitude of the changes in lower limb robusticity over time, the percent difference in average TA and J between consecutive time periods was calculated. This was achieved using the following formula and expresses the overall increase or decrease between successive time periods as a percentage.

$$\%Difference = \frac{Later\ time\ period\ mean - Earlier\ time\ period\ mean}{Earlier\ time\ period\ mean} * 100$$

7.4 Results

The following presents the results of the analysis of CSG properties of the femur and tibia during the Neolithic and Copper Age in the central Mediterranean. The investigation of long-term trends in mid-shaft cross-section area (TA) and shape (I_{max}/I_{min}) in the femur and tibia are presented first, in order to provide a broader temporal context for the focused spatial analysis of solid CSG properties (TA, J and I_{max}/I_{min}) in the Neolithic and Copper Age. Although not discussed in the main analysis, descriptive statistics and box-and-whisker plots for individual SMA properties (I_{max}, I_{min}, I_x, I_y) are provided in Appendix D for the femur (Tables D.1-D.2; Figures D.1-D.4) and tibia (Table D.3-D.4; Figures D.5-D.8).

7.4.1 Long-term trends in lower limb robusticity

Descriptive statistics for femoral and tibial mid-shaft TA and I_{max}/I_{min} from the Upper Palaeolithic to the Modern periods are presented by bone, sex and time period in Table 7.3. Table 7.4 displays the results of the one-way ANOVA tests and *post-hoc* comparisons investigating TA and I_{max}/I_{min} in the lower limb between time periods (pooled sex samples). Box-and-whisker plots displaying temporal trends in femoral and tibial CSG properties (pooled sex) are displayed in Figures 7.2 and 7.3. Temporal trends in males and females were explored with one-way ANOVA tests and the results of the *post-hoc* comparisons are presented in Table 7.5. Box-and-whisker plots displaying temporal trends in TA and I_{max}/I_{min} in the femur and tibia by time period and sex are displayed in Figures 7.4-7.7.

Using TA as a proxy for diaphyseal rigidity, the results of the one-way ANOVA show overall consistency in lower limb robusticity between the pooled sex Upper Palaeolithic, Mesolithic, Neolithic and Copper Age samples, whilst the Bronze Age signals a period of much reduced lower limb robusticity (Table 7.3; Table 7.4). Given the small and unequal sample sizes, the results cannot be considered statistically conclusive and it is important to supplement the analysis with consideration of the summary statistics. The descriptive statistics show a slight increase in mean TA in the femur and tibia from the Upper Palaeolithic to the Mesolithic period

(Table 7.3), followed by a decline in mean *TA* values from the Mesolithic to the Copper Age (Table 7.3; Figure 7.2a; Figure 7.3a).

Table 7.3: Summary statistics for mid-shaft (50%) CSG properties of the femur and tibia by sex and time period.

	Femur						Tibia					
	N	*TA*			I_{max}/I_{min}		*N*	*TA*			I_{max}/I_{min}	
		Mean	**St.D.**	**%Diff**[b]	**Mean**	**St.D.**		**Mean**	**St.D.**	**%Diff.**[b]	**Mean**	**St.D.**
Pooled sex w/disarticulated samples												
Upper Pal.	25	914.52	99.08		1.52	0.20	17	790.88	57.87		2.51	0.67
Mesolithic	22	923.8	99.79	1.01	1.38	0.26	17	803.18	102.24	1.56	2.38	0.58
Neolithic[a]	39	868.41	107.88	-6.00	1.30	0.22	51	768.43	117.61	-4.33	2.34	0.41
Copper Age[a]	114	856.61	107.67	-1.36	1.30	0.17	104	719.58	98.68	-6.36	2.34	0.44
Bronze Age	31	762.87	91.11	-10.94	1.33	0.22	30	642.93	100.86	-10.65	2.43	0.53
Roman	34	907.23	118.55	18.92	1.30	0.16	30	728.47	129.22	13.30	2.16	0.51
Medieval	41	867.15	103.42	-4.42	1.33	0.19	38	674.05	108.29	-7.47	2.03	0.43
Modern	32	855.13	104.73	-1.39	1.37	0.27	30	666.43	66.82	-1.13	2.10	0.48
Males												
Upper Pal.	16	927.94	106.549		1.55	0.22	11	805.91	62.64		2.81	0.62
Mesolithic	19	952.74	89.922	2.67	1.43	0.27	14	834.21	81.59	3.51	2.48	0.55
Neolithic	15	905.29	121.059	-4.98	1.40	0.27	23	807.61	101.58	-3.19	2.53	0.42
Copper Age	23	889.17	84.114	-1.78	1.32	0.20	21	757.84	75.05	-6.16	2.34	0.42
Bronze Age	17	782.82	82.496	-11.96	1.30	0.15	15	708.93	85.01	-6.45	2.51	0.38
Roman	18	931.75	111.588	19.02	1.31	0.18	17	761.88	127.68	7.47	2.31	0.55
Medieval	25	891.32	112.132	-4.34	1.37	0.20	22	694.45	129.14	-8.85	2.05	0.42
Modern	22	867.45	92.923	-2.68	1.31	0.14	20	672.55	67.03	-3.15	2.13	0.52
Females												
Upper Pal.	9	890.67	84.657		1.45	0.17	6	763.33	38.26		1.97	0.36
Mesolithic	6	832.17	73.692	-6.57	1.19	0.08	3	658.33	46.18	-13.76	1.97	0.60
Neolithic	7	839.02	79.92	0.82	1.20	0.16	6	708.82	50.48	7.67	2.37	0.39
Copper Age	13	841.76	89.109	0.33	1.30	0.15	13	660.07	72.16	-6.88	2.58	0.39
Bronze Age	14	738.64	98.108	-12.25	1.37	0.28	15	576.93	67.16	-12.60	2.34	0.65
Roman	15	881.07	123.902	19.28	1.29	0.14	13	684.77	122.35	18.69	1.96	0.38
Medieval	16	829.38	76.87	-5.87	1.27	0.18	16	646	64.23	-5.66	1.99	0.46
Modern	10	828.00	128.225	-0.17	1.52	0.40	10	654.2	68.21	1.27	2.03	0.39

[a]Contains disarticulated assemblages. Upper Pal. = Upper Palaeolithic.

[b]Percent difference in *TA* calculated as ((Earlier average-Later average)/Earlier average)*100. Positive values indicate a temporal increase, negative values indicate a temporal decrease.

The results of the one-way ANOVA tests comparing mid-shaft *TA* and I_{max}/I_{min} in the femur and tibia between the Neolithic and Copper Age showed no difference between the two time periods (Table 7.4). There is, however, a more noticeable decline in mean *TA* in the tibia during the Copper Age (Table 7.3, Figure 7.3a), which is also reflected in the percent difference (Femur = 1.36% decrease, tibia *TA* = 6.36% decrease). After the Copper Age, there is a significant drop in *TA* (Femur = 10.94% decrease, tibia *TA* = 10.65% decrease) in the Bronze

Age. This decline is most obvious in the femur, with the Bronze Age sample displaying lower ($p<0.05$) femoral mid-shaft *TA* than all other time periods. In the tibia, a steady reduction in *TA* is observed from the Mesolithic onwards (Figure 7.2a; Figure 7.3a), but the Bronze Age sample also displays considerably lower tibial *TA* than the preceding Upper Palaeolithic ($p<0.001$), Mesolithic ($p<0.001$), Neolithic ($p<0.001$) and Copper Age ($p=0.010$) time periods (Table 7.4). Figures 7.2 and 7.3 clearly illustrate that the Bronze Age signals a period of much reduced lower limb robusticity, as there is a subsequent increase in mean *TA* in the femur ($p<0.001$) and tibia ($p=0.038$) in the Roman period (Table 7.3; Table 7.4), before the resumption of a gradual decline throughout the Medieval and Modern periods (Table 7.3).

Table 7.4: Summary of one-way ANOVA and post-hoc (Hochberg GT2[b] and Games-Howell[c]) tests investigating variation in mid-shaft CSG properties of the femur and tibia by time period.

Time period	Femur *TA* (50%)	Femur I_{max}/I_{min} (50%)	Tibia *TA* (50%)	Tibia I_{max}/I_{min} (50%)
	Sig.difference[a,b]	*Sig. difference*[a,c]	*Sig. difference*[a,b]	*Sig. difference*[a,b]
Upper Pal.	BA	NEO, CA, BA, RO, MED	BA, MED, MOD	MED
Mesolithic	BA		BA, MED, MOD	
Neolithic	BA	UP	BA, MED, MOD	
Copper Age	BA	UP	BA	MED
Bronze Age	UP, MESO, NEO, CA, RO, MED, MOD	UP	UP, MESO, NEO, CA, RO	MED
Roman	BA	UP	BA	
Medieval	BA	UP	UP, MESO, NEO	UP, CA, BA
Modern	BA		UP, MESO, NEO	

ANOVA	d.f	F	Sig.	d.f	F	Sig.	d.f	F	Sig.	d.f	F	Sig.
	7	6.921	<0.001	7	3.925	<0.001	7	9.039	<0.001	7	3.884	<0.001

[a] Alpha = <0.05. *Post-hoc* comparisons using Hochberg GT2[b] and Games-Howell[c] tests. Exact *p* values presented in Tables D.5-D.7 in Appendix D.
UP = Upper Palaeolithic, MESO = Mesolithic, Neo = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

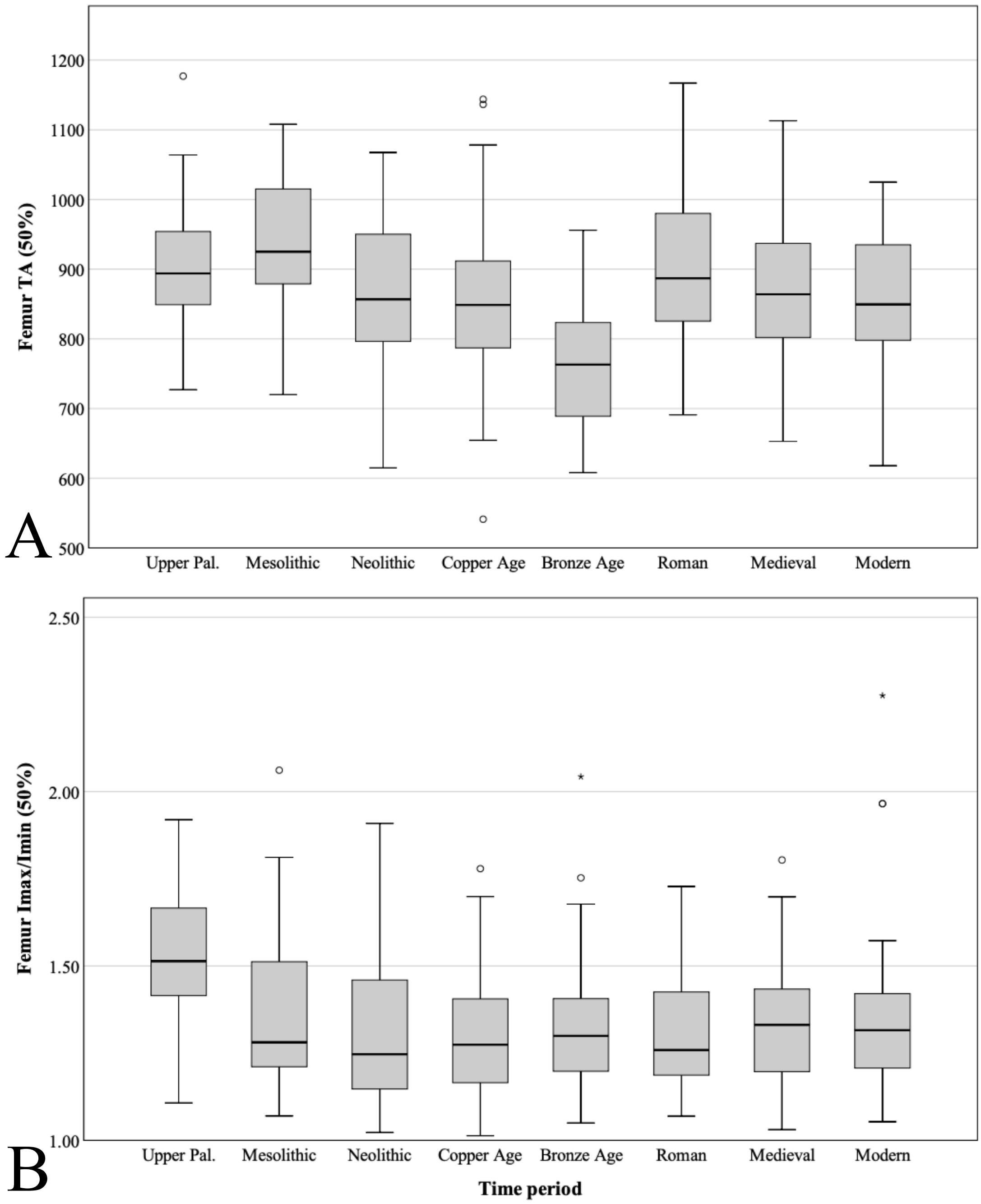


Figure 7.2 – Box-and-whisker plots showing temporal trends in A) total cross-sectional area (TA) and B) cross-section shape (I_{max}/I_{min}) at the mid-shaft of the femur (50%) from the Upper Palaeolithic to the Modern Period in the central Mediterranean (pooled sex samples).

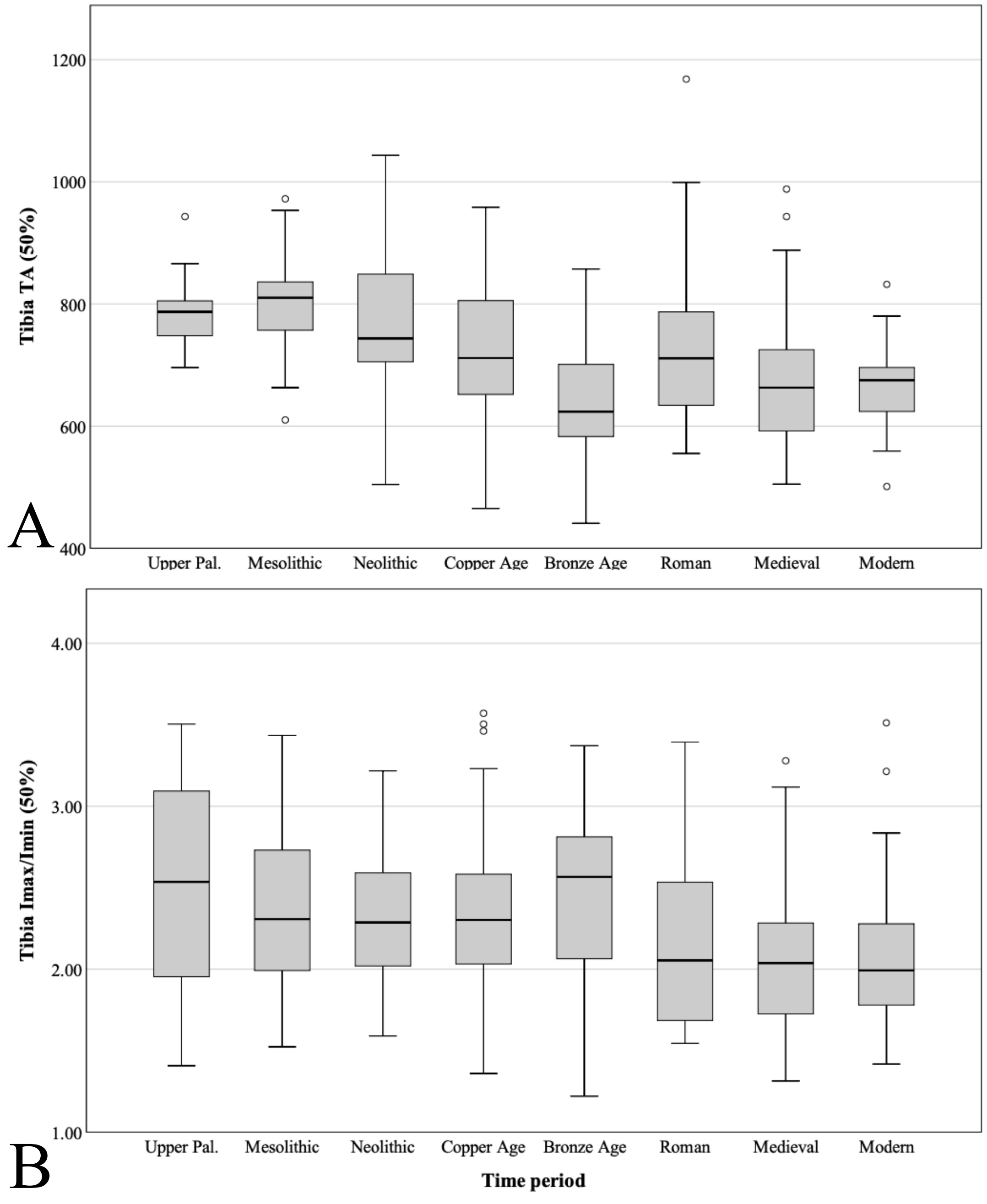


Figure 7.3 – Box-and-whisker plots showing temporal trends in A) total cross-sectional area (TA) and B) cross-section shape (I_{max}/I_{min}) at the mid-shaft of the tibia (50%) from the Upper Palaeolithic to the Modern Period in the central Mediterranean (pooled sex sample).

The analysis of cross-section shape charts an overall decline in I_{max}/I_{min} values in both the femur and tibia over time, reflecting a diachronic shift towards rounder cross-section shape. In the femur, a steep decline in I_{max}/I_{min} is seen from the Upper Palaeolithic to Neolithic, followed by relative consistency in cross-section shape from the Copper Age to the Modern period (Table 7.3; Figure 7.2b). In the tibia, the decline in I_{max}/I_{min} is more gradual from the Upper Palaeolithic to the Modern period (Table 7.3; Figure 7.3b). The Upper Palaeolithic sample displays the greatest I_{max}/I_{min} values (i.e. more elliptical) for the femur (mean = 1.52) and tibia (mean = 2.51). In the femur, the Upper Palaeolithic sample has higher mean values for I_{max}/I_{min} than the Neolithic (p= 0.005), Copper Age (p<0.001), Bronze Age (p= 0.032) Roman (p=0.002) and Medieval (p= 0.013) time periods. In the tibia, a similar overall broad decline in average I_{max}/I_{min} values is observed (Table 7.3), but there is a noticeable increase in the Bronze Age (Figure 7.3b). In general, the pooled sex analysis presented here shows a gradual decrease in both CSG properties in the femur and tibia throughout time, although the Bronze Age and Roman samples represent deviations to this broader temporal trend.

Table 7.5: Results of one-way ANOVA and post-hoc tests (Hochberg GT2[b] and Games-Howell[c]) exploring temporal trends in mid-shaft CSG properties of the femur and tibia in males and females.

		Femur		Tibia	
Time period		TA (50%)	Imax/Imin (50%)	TA (50%)	Imax/Imin (50%)
		Sig.difference [a,b]	*Sig. difference* [a,c]	*Sig. difference* [a,b]	*Sig. difference* [a,b]
Upper Pal.	Male	BA	CA, BA, RO, MOD	MOD	MED, MOD
	Females	BA	MESO	BA, MED	
Mesolithic	Male	BA		BA, MED, MOD	MED, MOD
	Females		UP		
Neolithic	Male	BA		MED, MOD	MED
	Females			BA	
Copper Age	Male	BA	UP		
	Females				RO, MED
Bronze Age	Male	UP, MESO, NEO, CA, RO, MED	UP	MESO	
	Females	UP, RO		UP, NEO	
Roman	Male	BA	UP		
	Females	BA			CA
Medieval	Male	BA		MESO, NEO	UP, MESO
	Females			UP	MED
Modern	Male		UP	UP, MESO, NEO	UP
	Females				

ANOVA	**d.f**	**F**	**Sig.**	**d.f**	**F**	**Sig.**	**d.f**	**F**	**Sig.**	**d.f**	**F**	**Sig.**
Male	7	4.777	<0.001	7	3.179	0.004	7	6.516	<0.001	7	4.123	<0.001
Female	7	2.814	0.011	7	2.519	0.021	7	5.094	<0.001	7	3.151	0.006

[a]Alpha = <0.05. *Post-hoc* comparisons using Hochberg GT2[b] and Games-Howell[c] tests. Exact p values presented in Tables D.7-D.10 in Appendix D.
UP = Upper Palaeolithic, MESO = Mesolithic, Neo = Neolithic, CA = Copper Age, BA = Bronze Age, RO = Roman, MED = Medieval, MOD = Modern.

Whilst the overall trends in mid-shaft *TA* and I_{max}/I_{min} in the femur and tibia occurred in both males and females, the one-way ANOVA tests (Table 7.5) and descriptive statistics (Table 7.3) reveal some subtle differences between the sexes. Generally, female tibiae exhibit much more temporal variation than males, exemplified by the percent differences between time periods (Table 7.3). Compared to the tibia, femoral CSG properties show less temporal variation in both sexes. In females, there is a decrease in average *TA* in the femur and tibia between the Upper Palaeolithic and Mesolithic, followed by a subsequent increase in the Neolithic (Table 7.3), although the pattern is more prominent in the tibia (Figure 7.6). In contrast, males show a slight increase in *TA* in the femur and tibia coming into the Mesolithic, followed by a decline in the Neolithic (Figures 7.4-7.6). The results reflect a divergence in lower limb loading between men and women during the Mesolithic. Between the Neolithic and the Copper Age, the results of the one-way ANOVAs show no significant temporal differences in *TA* and cross-section shape in either the femur or tibia among males and females (Table 7.5), as is reflected in the descriptive statistics (Table 7.3). In the femur, a slight decline in average *TA* values among males (1.78% decrease) coming into the Copper Age is in opposition to a slight increase in females (0.33% increase) (Figure 7.4; Table 7.3). The analysis of the tibia shows a slightly more pronounced decrease in mean *TA* between the Neolithic and Copper Age, although this was similar in both males (6.16% decrease) and females (6.88% decrease) (Table 7.3; Figure 7.6).

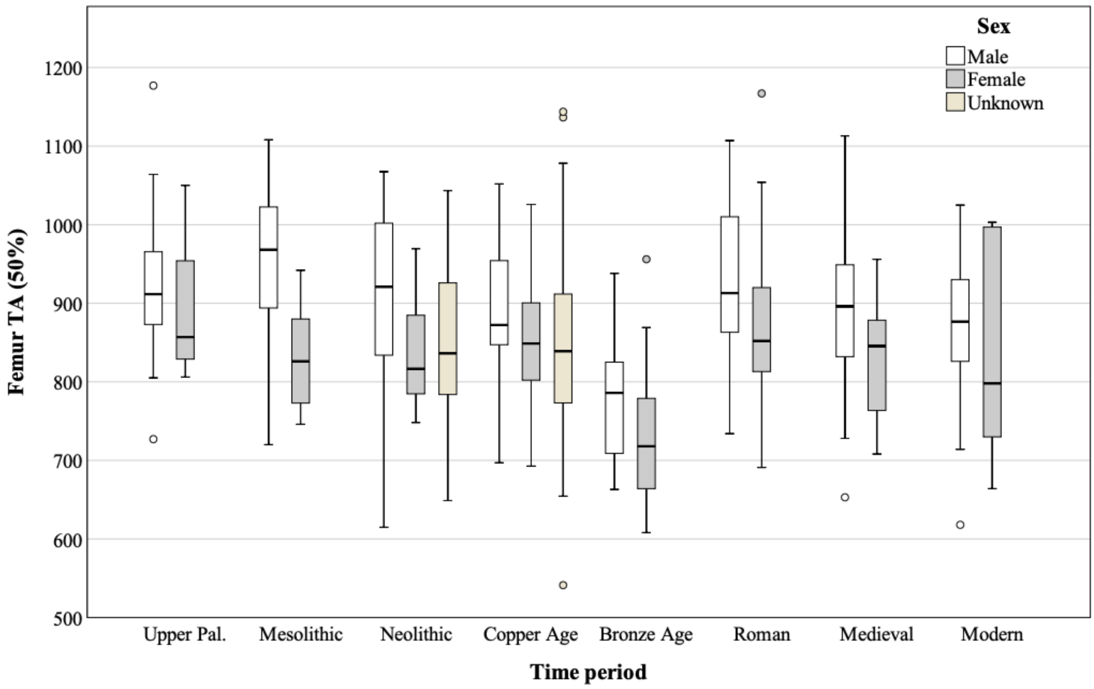


Figure 7.4 – Box-and-whisker plots showing temporal trends in total cross-section area (TA) at the mid-shaft of the femur (50%) from the Upper Palaeolithic to the Modern Period in the central Mediterranean.

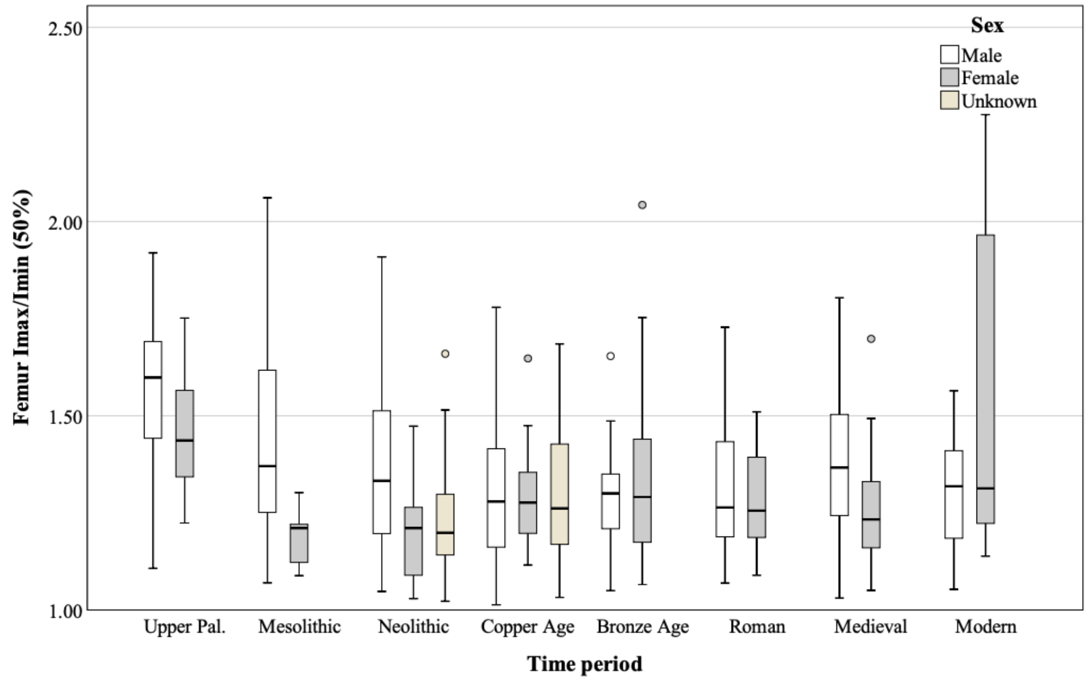


Figure 7.5 – Box-and-whisker plots showing temporal trends in cross-section shape (I_{max}/I_{min}) at the mid-shaft of the femur (50%) from the Upper Palaeolithic to the Modern Period in the central Mediterranean.

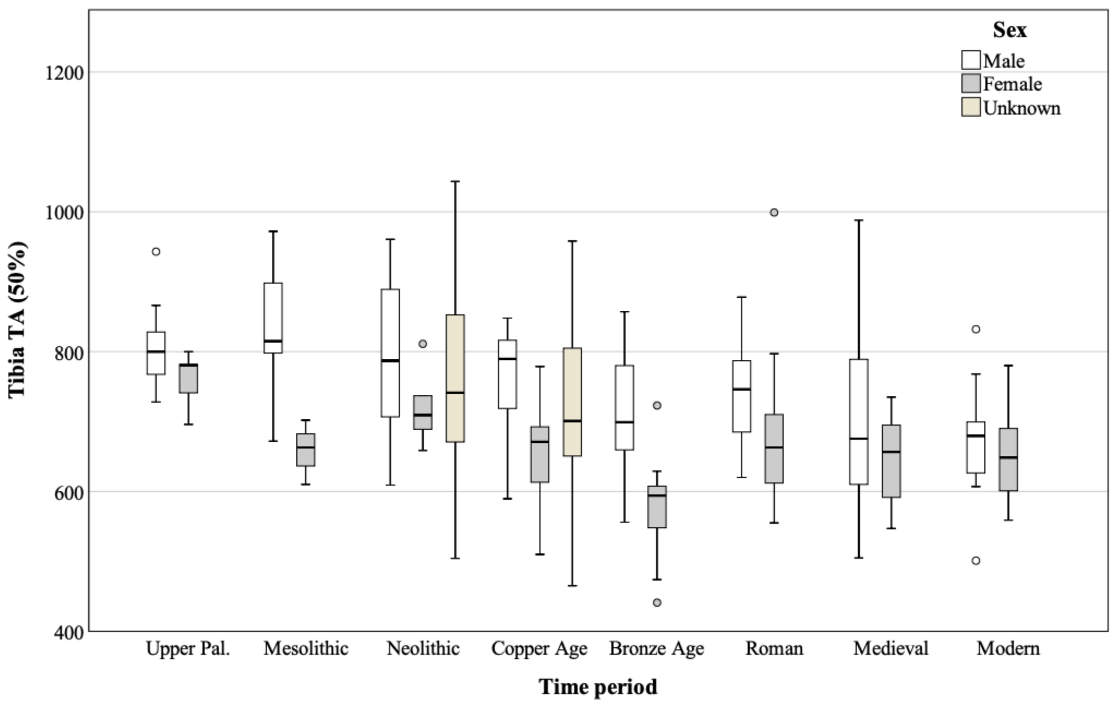


Figure 7.6 – Box-and-whisker plots showing temporal trends in total cross-section area (TA) at the mid-shaft of the tibia (50%) from the Upper Palaeolithic to the Modern Period in the central Mediterranean.

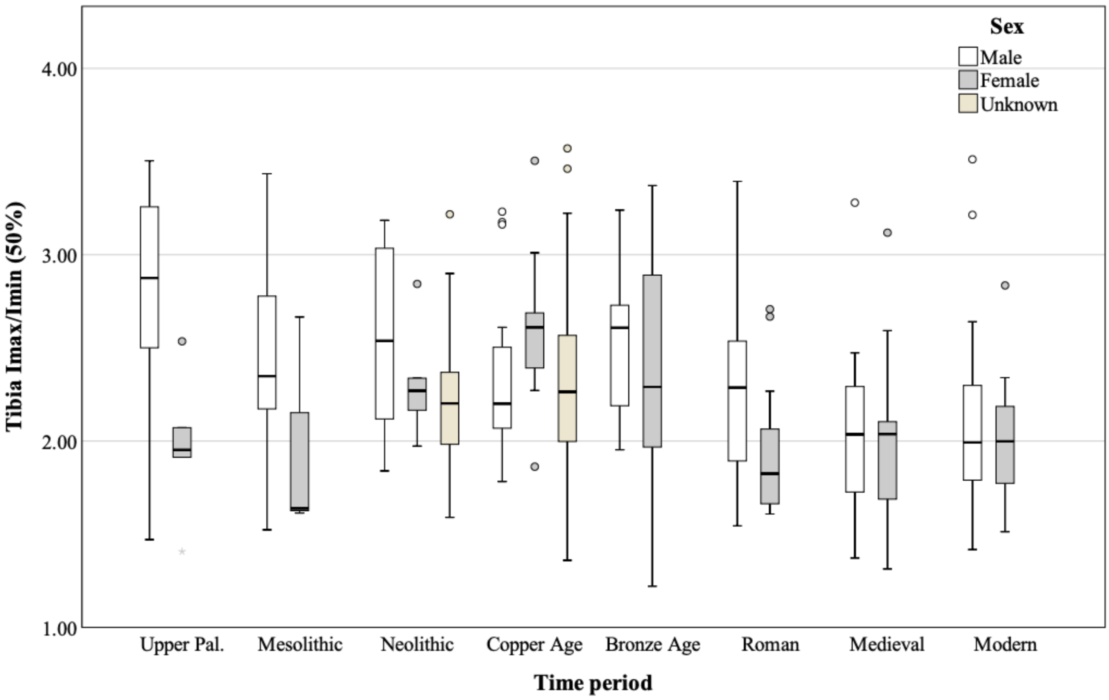


Figure 7.7 – Box-and-whisker plots showing temporal trends in cross-sectional shape (I_{max}/I_{min}) of the mid-shaft of the tibia (50%) from the Upper Palaeolithic to the Modern Period in the central Mediterranean.

As CSG properties for the Neolithic and Copper Age were all collected using the same solid method (see Chapter Six, Section 6.2), it is therefore possible to directly compare *J* values between the two time periods. This enables a more confident exploration of temporal change in lower limb rigidity between the two time periods that does not rely on using *TA* as a proxy. Table 7.6 displays the summary statistics and results of the independent *t*-tests used to explore differences in femoral and tibial *J* between the Neolithic and Copper Age. Figure 7.8 visualises the results as box-and-whisker plots. The results show an overall reduction in femoral (p=0.023) and tibial (p=0.027) rigidity (*J*) in the Copper Age, but both the independent *t*-tests and % differences indicate that this reduction was more prominent in males than females (Table 7.6; Figure 7.8). These results contradict the pattern observed in the analysis of mid-shaft *TA*, which suggested there was no overall decline in lower limb robusticity between the two periods.

Table 7.6: Summary statistics for differences in J at the mid-shaft of femur and tibia between the Neolithic and Copper Age by sex.

	Neolithic			Copper Age			% Difference[b]	Sig. temporal difference[a]
	N	Mean	St.d.	*N*	Mean	St.d.		
Pooled sex[c]								
Femur *J* (50%)	39	4257.12	944.14	114	3919.19	872.56	-7.94	**0.043**
Tibia *J* (50%)	51	4974.56	1277.57	104	4539.76	1079.11	-8.74	**0.028**
Males								
Femur *J* (50%)	15	4755.62	1034.24	23	3982.75	714.81	-16.25	**0.010**
Tibia *J* (50%)	18	5563.12	1181.41	21	4646.56	947.14	-16.48	**0.011**
Females								
Femur *J* (50%)	7	3908.03	630.99	13	3798.53	950.91	-2.80	0.788
Tibia *J* (50%)	6	4311.67	501.65	13	3719.55	759.68	-13.73	0.102

[a] Alpha = <0.05, significant differences are highlighted in bold.

[b] Percent difference calculated as ((Neolithic-Copper Age)/Neolithic)*100

[c] *With commingled samples included*

As with the pooled sex analysis, the results show that after the Copper Age there was a significant decrease in *TA* in the femur and tibia during the Bronze Age in both sexes (Table 7.3; Figure 7.3). The decline in lower limb rigidity among Bronze Age males is most apparent in the femur, with *TA* values considerably lower than those in the preceding Upper Palaeolithic (p=0.006), Mesolithic (p<0.001), Neolithic (p=0.025) and Copper Age (p=0.031) periods (Table 7.5). The Bronze Age also saw a greater reduction (12.6% decrease) in average tibial *TA* in females than in males (6.45% decrease) (Table 7.3). The analysis of cross-section shape documents a temporal decrease in I_{max}/I_{min} values, particularly among males, and indicates that mid-shaft cross-section shape became more circular over time. Within the tibia, the diminution in I_{max}/I_{min} can be more confidently assigned to a decline in antero-posterior loading, which when viewed alongside the temporal trends in *TA*, indicates an overall decrease in bending rigidity through time, although the increase in tibial I_{max}/I_{min} among Bronze Age males is interesting (Figure 7.7). The standard deviations show that males generally exhibit greater within-group variation in *TA* and I_{max}/I_{min} in the femur and tibia in all time periods, with the exception of Bronze Age and Modern period femora (Table 7.3; Figures 7.4-7.7).

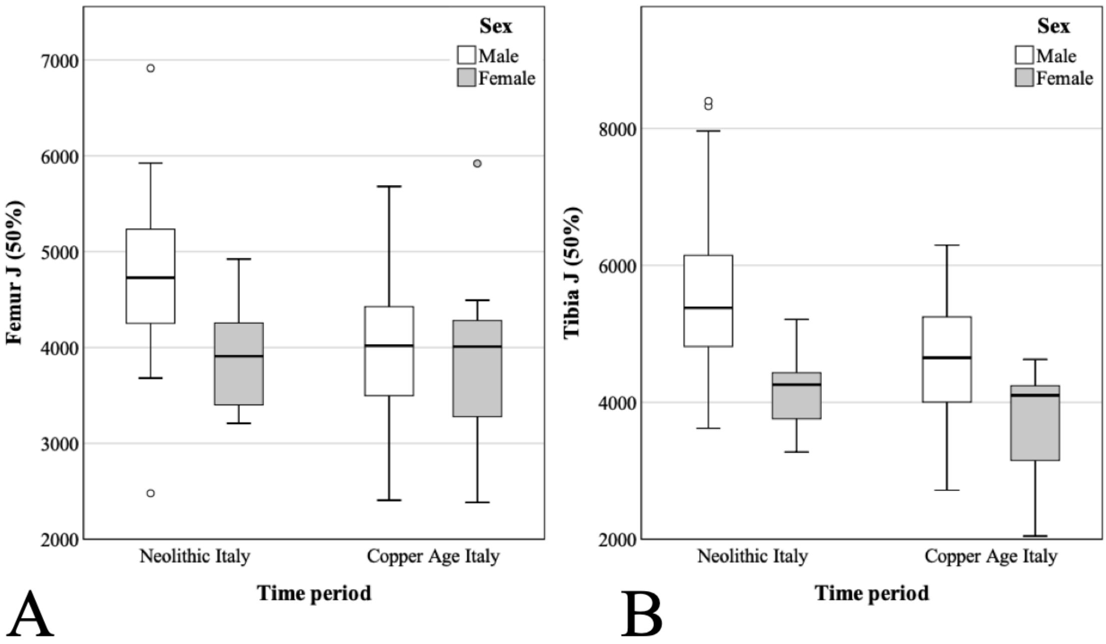


Figure 7.8 – Rigidity (J) in the femur (A) and tibia (B) across the Neolithic and Copper Age by sex.

7.4.2 Spatial and temporal analysis of the femur in the Neolithic and Copper Age

Summary statistics for *TA*, *J* and I_{max}/I_{min} at the mid-shaft of the femur are presented in Table 7.7 by sample. The results of the one-way ANOVA and *post-hoc* comparisons are presented in Table 7.8, with all solid CSG properties visualised in box-and-whisker plots in Figures 7.9-7.11. The S. Italian Neolithic sample did not have sufficiently preserved femora and therefore was not included in the spatial analysis of femoral CSG. The results of the one-way ANOVA revealed little sample variation within the Neolithic and Copper Age time periods in any of the CSG properties of the mid-shaft femur (Table 7.8). The mean values and standard deviations for *TA*, *J* and I_{max}/I_{min} also reflect the homogeneity in the morphology of the femur between the samples (Table 7.7). Of all the samples, the Neolithic N. Italian and Maltese assemblages display the highest mean *TA* and *J* values, and among the greatest mean values for I_{max}/I_{min}. Conversely, the Alpine Beaker sample features low average values for *TA* and *J*, alongside lower I_{max}/I_{min} values, suggesting decreased femoral loading (Table 7.7; Figures 7.9-7.11). The box-and-whisker plots also show limited within-group variation in *TA* and *J* among the Alpine Beaker sample (Figures 7.9-7.10), although the presence of outliers in the data masks this from being observed in the standard deviations (Table 7.7).

Table 7.7: Summary statistics for mid-shaft CSG properties of the femur between the individual Neolithic and Copper Age samples (pooled sex).*

Sample		**TA**		***J***		I_{max}/I_{min}	
	N	Mean	St.d	Mean	St.d	Mean	St.d
Neolithic N. Italy	24	879.97	122.41	4426.34	1093.20	1.32	0.25
Neolithic Sardinia	15	850.67	81.59	3986.38	573.17	1.28	0.17
Copper Age c. Italy	32	871.75	87.07	3947.54	827.837	1.31	0.17
Copper Age Po Valley	8	864.52	104.74	3822.73	648.81	1.36	0.20
Late Neolithic Malta	31	882.71	108.57	4097.71	958.285	1.31	0.18
Copper Age Sardinia	30	838.27	105.89	3818.07	952.685	1.28	0.17
Alpine Beaker	13	793.12	137.82	3716.44	709.658	1.27	0.14

*S. Italian Neolithic sample did not have sufficiently preserved femora

Table 7.8: Results of one-way ANOVA and post-hoc comparisons of mid-shaft CSG properties of the femur by sample.

Sample	***TA (50%)***			***J (50%)***			I_{max}/I_{min} ***(50%)***		
	Sig. *post-hoc* difference[b]			Sig. *post-hoc* difference[b]			Sig. *post-hoc* difference[b]		
Neolithic N. Italy									
Neolithic Sardinia									
Copper Age c.Italy									
Copper Age Po Valley									
Late Neolithic Malta									
Copper Age Sardinia									
Alpine Beaker									
ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
Time period[a]	6	1.515	0.177	6	1.473	0.191	6	0.360	0.903

[a] Alpha = <0.05. [b] Post-hoc tests using Games-Howell, exact *p* values presented in Table D.11 in Appendix D.

NEONI = Neolithic N. Italy, NEOSI = Neolithic S. Italy, NEOSA = Neolithic Sardinia, CACI = Copper Age central Italy, CAPV - Copper Age Po Valley, LNM = Late Neolithic Malta, CAS = Copper Age Sardinia, APB = Alpine Beaker.

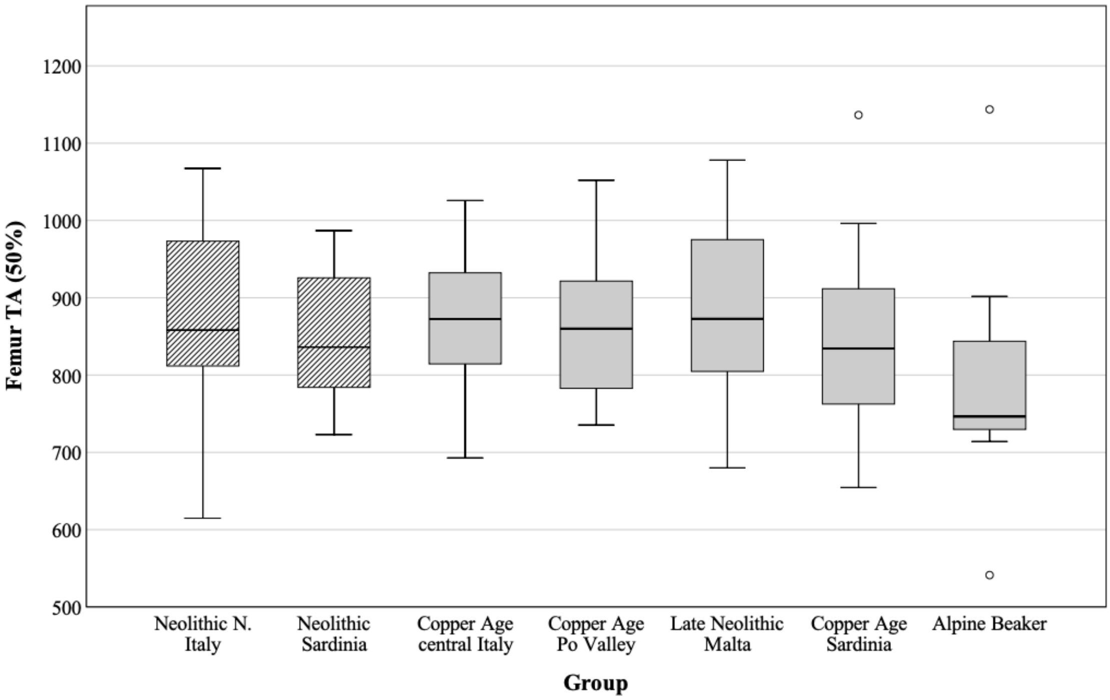


Figure 7.9 – Box-and-whisker plots showing spatial variation in total cross-sectional area (TA) at the mid-shaft (50%) of the femur between the pooled sex Neolithic and Copper Age/Late Neolithic groups analysed in this study (samples ordered chronologically, Neolithic groups denoted by diagonal lines).

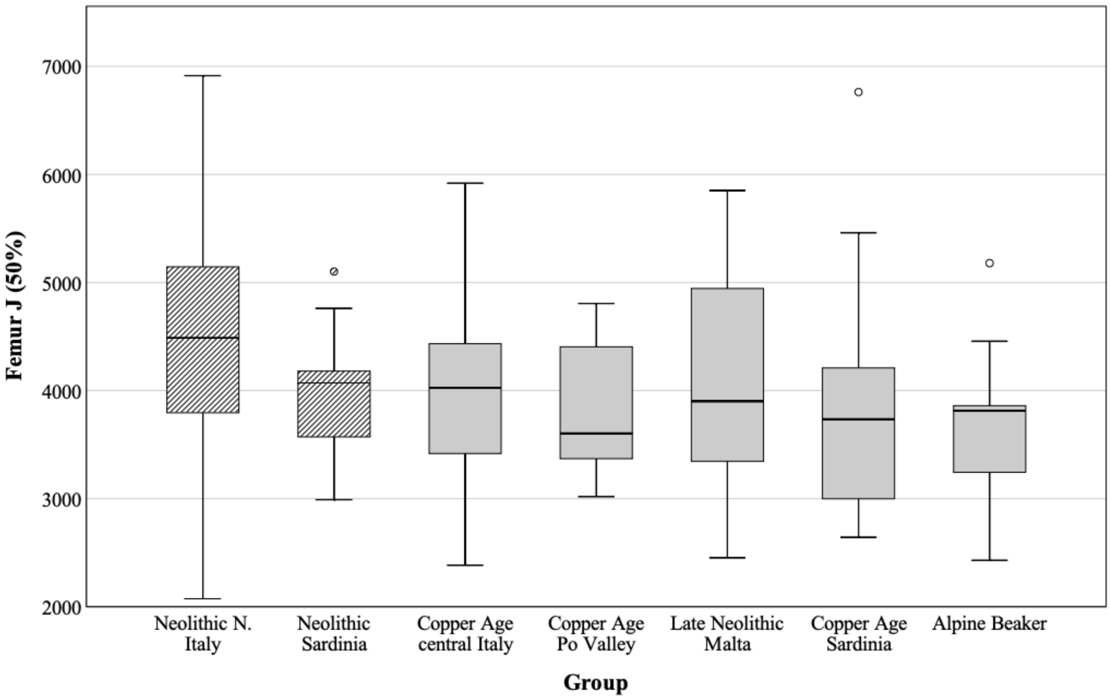


Figure 7.10 – Box-and-whisker plots showing spatial variation in mid-shaft (50%) femoral rigidity (J) between the pooled sex Neolithic and Copper Age/Late Neolithic groups analysed in this study (samples ordered chronologically, Neolithic groups denoted by shading lines).

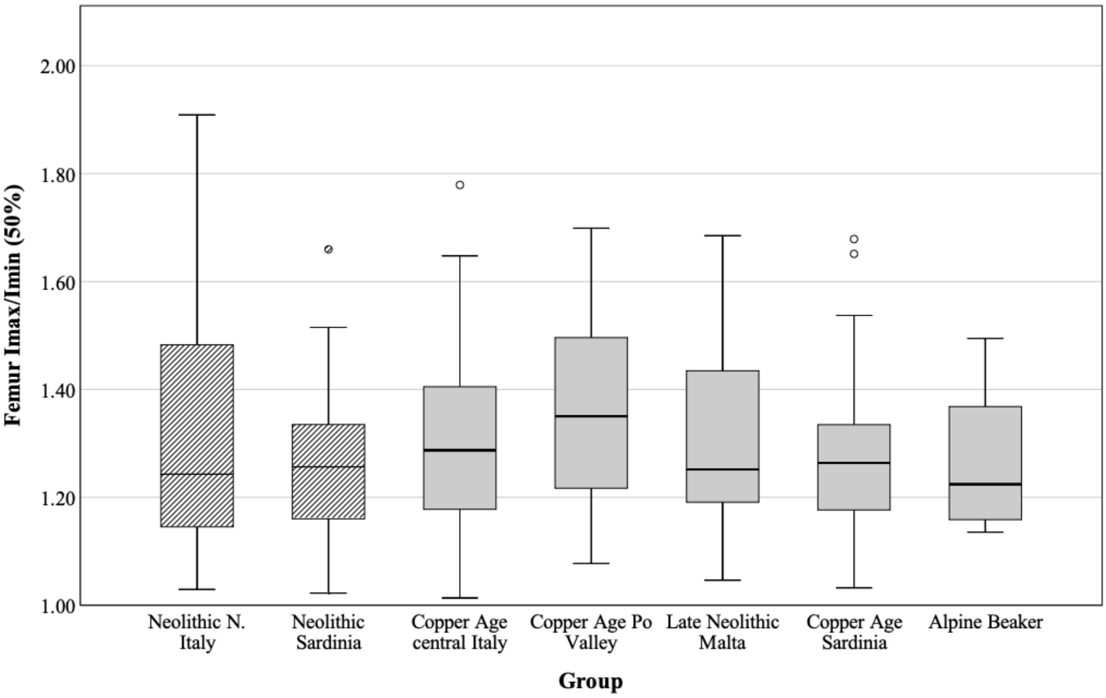


Figure 7.11 – Box-and-whisker plots showing spatial variation in cross-section shape (I_{max}/I_{min}) at the mid-shaft (50%) of the femur between the pooled sex Neolithic and Copper Age/Late Neolithic groups analysed in this study (samples ordered chronologically, Neolithic groups denoted with shading).

7.4.3 Spatial and temporal analysis of the tibia in the Neolithic and Copper Age

The analysis of mid-shaft solid CSG properties of the tibia documented greater variability between samples than the analysis of the femur. Descriptive statistics for *TA*, *J* and I_{max}/I_{min} at the mid-shaft of the tibia are displayed in Table 7.9 and the results of the one-way ANOVA tests and pairwise comparisons are summarised in Table 7.10. Box-and-whisker plots for all solid CSG properties are presented in Figures 7.12-7.14. No significant differences in *TA*, *J* and I_{max}/I_{min} were observed between any of the samples (Table 7.10), although consideration of the summary statistics reveals some underlying differences (Table 7.9).

Table 7.9: Summary statistics for mid-shaft (50%) CSG properties of tibia by sample (pooled sex).

Sample	***N***	**TA**		***J***		I_x/I_y	
		Mean	St.d	Mean	St.d	Mean	St.d
Neolithic N. Italy	27	759.84	108.63	5073.02	1238.63	2.45	0.41
Neolithic S. Italy	9	783.13	107.83	5251.66	1617.23	2.50	0.40
Neolithic Sardinia	15	775.54	144.98	4631.07	1136.22	2.04	0.26
Copper Age C. Italy	32	717.48	90.25	4264.15	1039.62	2.43	0.44
Copper Age Po Valley	5	682.58	83.00	3964.58	757.18	2.58	0.36
Late Neolithic Malta	27	713.10	106.42	4419.80	939.52	2.29	0.52
Copper Age Sardinia	27	730.68	106.30	4979.73	1176.03	2.41	0.39
Alpine Beaker	13	729.37	100.81	4774.81	1111.13	2.02	0.28

Table 7.10: Results of one-way ANOVA and post-hoc comparisons of mid-shaft CSG properties of the tibia between samples.

Sample	***TA (50%)***			***J (50%)***			***Imax/Imin (50%)***		
	Sig. *post-hoc* difference[a,c]			Sig. *post-hoc* difference[a,c]			Sig. *post-hoc* difference[a,c]		
Neolithic N. Italy									
Neolithic S. Italy									
Neolithic Sardinia									
Copper Age C. Italy									
Copper Age Po Valley									
Late Neolithic Malta									
Copper Age Sardinia									
Alpine Beaker									
ANOVA	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**	**d.f.**	**F**	**Sig.**
	7	1.23	0.291	7	2.19	0.039	7	3.30	0.003

[a] Alpha = <0.05. *Post-hoc* tests using Hochberg GT2[b] and Games-Howell[c], exact *p* values presented in Table D.12 in Appendix D.
NEONI = Neolithic N. Italy, NEOSI = Neolithic S. Italy, NEOSA = Neolithic Sardinia, CACI = Copper Age central Italy, CAPV = Copper Age Po Valley, LNM = Late Neolithic Malta, CAS = Copper Age Sardinia, APB = Alpine Beaker.

The Sardinian, N. Italian and S. Italian Neolithic samples display the highest mean values for tibial *TA* and *J*, with the latter exhibiting the highest average for *J* across all samples (Table 7.9; Figures 7.12-7.13). In general, the Copper Age and Late Neolithic Maltese samples have lower mean values for *TA* and *J* than the Neolithic samples (Table 7.9; Figures 7.12-7.13). Whilst this is reflective of the overall decrease in femoral and tibial *J* between the two periods (Section 7.5.1; Figure 7.8), when considering each Copper Age sample in isolation there is some overlap between some Neolithic and Copper Age samples – notably the Copper Age Sardinians and Alpine Beakers. The box-and-whisker plots and descriptive statistics also highlight underlying spatial variation between the Copper Age samples. The Copper Age Po Valley sample has the lowest mean values for *TA* and *J* in the tibia, as well as the greatest mean I_{max}/I_{min} values out of all samples analysed, especially compared to the Neolithic samples. The Po Valley group also exhibits extremely limited within-group variation in all CSG properties of the tibia, which mirrors the limited within-group variation observed in the humeri of this sample (Chapter Three, Section 3.4.3). Interestingly, the Maltese sample does not show any major differences in mid-shaft CSG properties of the tibia with any of the earlier Neolithic or coeval Copper Age samples (Table 7.9; Figures 7.12-7.14).

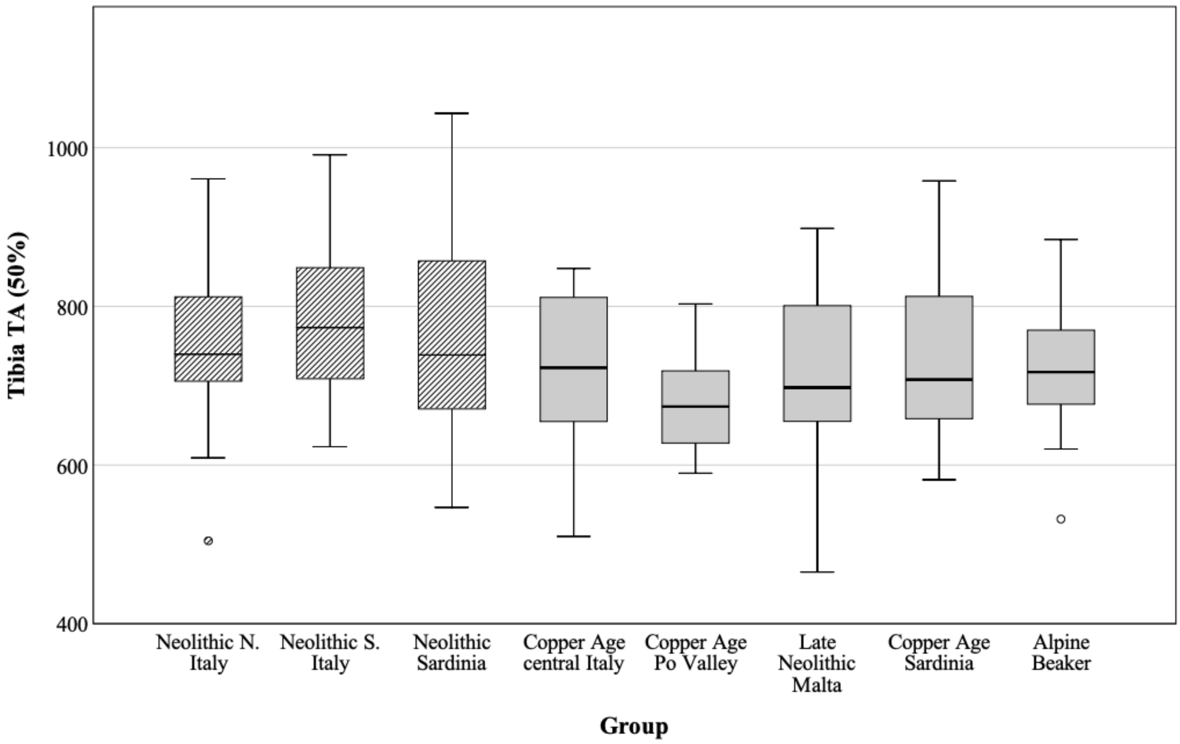


Figure 7.12 – Box-and-whisker plots showing spatial variation in total cross-sectional area (TA) at the mid-shaft of the tibia (50%) between the pooled sex Neolithic and Copper Age/Late Neolithic groups analysed in this study (samples ordered chronologically, Neolithic groups denoted by shading lines).

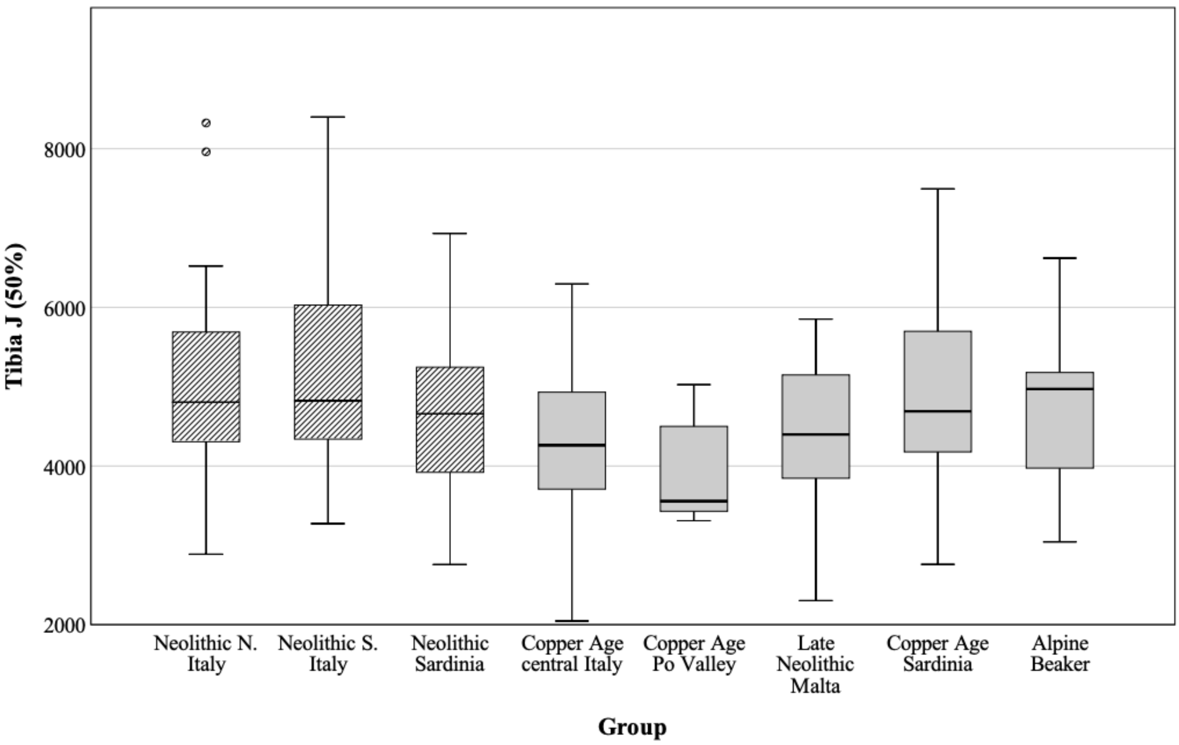


Figure 7.13 – Box-and-whisker plots showing spatial variation in mid-shaft (50%) femoral rigidity (J) between the pooled sex Neolithic and Copper Age/Late Neolithic groups analysed in this study (samples ordered chronologically, Neolithic groups denoted by diagonal lines).

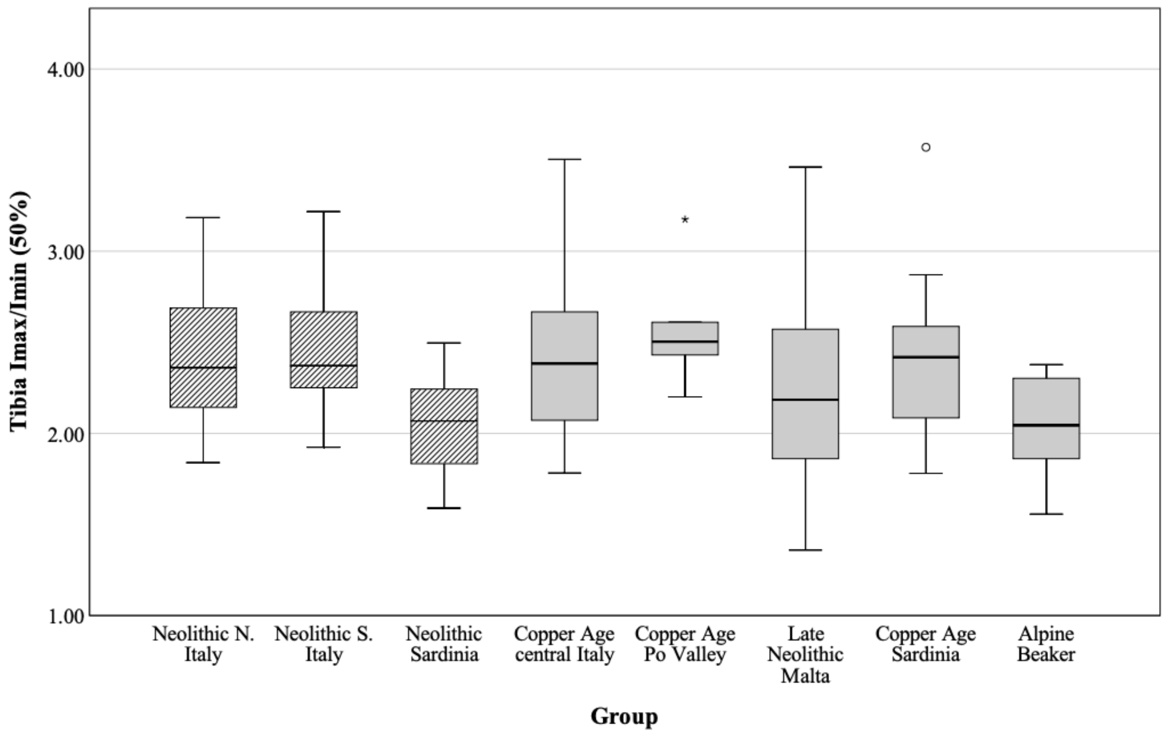


Figure 7.14 – Box-and-whisker plots showing spatial variation in cross-sectional shape (I_{max}/I_{min}) of the mid-shaft tibia (50%) between the pooled sex Neolithic and Copper Age/Late Neolithic groups analysed in this study (samples ordered chronologically, Neolithic groups denoted by diagonal lines).

The one-way ANOVA tests showed no spatial differences in mid-shaft cross-section shape in the tibia, but descriptive statistics and box-and-whisker plots document underlying differences between the individual samples (Table 7.9; Figure 7.14). Among the Neolithic samples, the Sardinians display lower values and limited variability in I_{max}/I_{min}, reflecting rounder diaphyseal cross-sections than the N. Italian and S. Italian groups (Table 7.9; Figure 7.14). Within the Copper Age groups, the Alpine Beakers have considerably rounder cross-section shape than coeval samples, especially those from Sardinia, central Italy and the Po Valley (Figure 7.14). In Sardinia, there is a slight temporal increase in I_{max}/I_{min} from the Neolithic to the Copper Age (Table 7.9-7.10), which indicates a shift to more elliptical cross-section shape suggesting greater loading in the antero-posterior plane. Both Sardinian groups exhibit similar within-group variation in CSG properties of the tibia. Whilst the analysis revealed subtle spatial differences between the Neolithic and Copper Age groups, the level of variation is much less than what might have been expected in light of the considerable differences in landscape context between samples.

7.5 Discussion

This chapter examined lower limb robusticity in the central Mediterranean Neolithic and Copper Age through analysis of mid-shaft CSG properties of the femur and tibia in order to investigate whether there was a change in mobility behaviour between the two time periods. Analysis of comparative data spanning the Upper Palaeolithic to the Modern periods was also included in order to frame the Neolithic and Copper Age data within a broader temporal context. It was proposed in Chapter One that a gradual decrease in lower limb robusticity would be observed across the Late Pleistocene and Holocene, but that the timing of marked reductions in lower limb robusticity after the introduction of agriculture would differ from wider Europe. This assumption was based on previous research on central Mediterranean Neolithic groups in northern Italy and southern France (Lambert *et al.*, 2013; Marchi *et al.*, 2006; Ruff *et al.*, 2006a) and Robb's (1994c) hypothesis that Copper Age groups might exhibit evidence for high levels of terrestrial mobility. It was also hypothesised that there would be regional variation in lower limb CSG properties within the Neolithic and Copper Age as a result of the considerable differences in landscape setting, settlement patterns and subsistence strategy between samples. The results of this chapter showed that the ca. 24,000 years represented by this study are indeed characterised by a progressive decline in lower limb robusticity, although there were some differences in how these long-term trends played out between the sexes. As part of this gradual decline, a decrease in femoral and tibial robusticity was observed between the Neolithic and the Copper Age, leading to a period of much reduced lower limb robusticity in the Bronze Age.

The analysis of spatial variation within the Neolithic and Copper Age showed a surprising lack of sample variation, contrary to expectation.

7.5.1 Temporal trends in the lower limb

The polar second moments of area (*J*) is commonly used to explore long bone rigidity and robusticity in biomechanical studies of mobility. The analysis of long-term trends in lower limb robusticity presented in this chapter relied on total cross-section area (*TA*) as a proxy for long bone rigidity, as it is highly correlated with *J* (Stock and Shaw, 2007). The pooled sex analysis showed that there was a significant reduction in *J*, but not *TA*, between the Neolithic and Copper Age. The investigation of sex-specific trends showed that the rate of decline in *TA* was similar in both males and females, whilst the analysis of *J* indicated that there was a more pronounced decline in lower limb robusticity in males. The contrasting results reported in the analysis of *TA* and *J* between the Neolithic and Copper Age underscore the fact that whilst both properties are highly correlated, the different standardisation methods that are required for each property can lead to differing outcomes. Ultimately, *J* is a more accurate indicator of bone bending rigidity (Ruff, 2019). However, the long-term trends in *TA* are still important and can be considered to accurately reflect broad changes in lower limb robusticity and aid in contextualising the Neolithic and Copper Age data.

Whilst analysis of *J* across all time periods would have been ideal, the use of regression formulae to convert solid CSG properties to true CSG properties was avoided (as with the upper limb) given the already challenging nature of working with commingled and fragmented long bones, which require various estimates to be made during the data processing stage (see Chapter Four; see Chapter Six for discussions on conversion formulae). Instead, CSG properties that are directly comparable between two methods were used. Total cross-section area (*TA*) is the same between the solid and hollow methods, whilst I_{max}/I_{min} shape indices derived from both methods have been shown to be highly correlated (Davies *et al.*, 2012; Macintosh *et al.*, 2013; Sparacello and Pearson, 2010; Stock and Shaw, 2007). Comparing *TA* and I_{max}/I_{min} values from the Neolithic and Copper Age samples collected as part of this study with those from Ruff (2018c), therefore, provides a good approximation of long-term trends in lower limb morphology in the absence of comprehensive solid CSG comparative data. However, future research should aim to explore the trends discussed below using directly comparable CSG data.

The temporal analysis of total cross-section area (*TA*) and shape (I_{max}/I_{min}) in the mid-shaft of the femur and tibia supports the expectation that there was a decrease in lower limb robusticity throughout the Late Pleistocene and Holocene, but also suggest that the Bronze Age was a period of particularly reduced terrestrial mobility. Lower limb robusticity then increased again in the Roman period, before the resumption of a gradual decline in the Medieval and Modern periods. The results from the tibia offer the clearest picture of this trend, which is to be expected given that tibiae are more sensitive to changes in mobility behaviour, whilst femoral cross-sections have been shown to be susceptible to variation in body breadth (Davies and Stock, 2014; Shaw and Stock, 2011; Stock, 2006; Ruff *et al.*, 2006a). As result, femoral CSG properties may be of limited interpretive value when applied to commingled samples, where the body breadth of an individual cannot be accounted for. The increase in lower limb robusticity during the Roman period is interesting, as it mirrors the results of the analysis of body size (Chapter Six) and upper limb robusticity (Chapter Six). Together, the results indicate that the Roman period was a time of overall elevated post-cranial robusticity, but decreased nutritional status, and mirrors the overall patterns seen in the Neolithic.

The overall temporal decline in lower limb robusticity from the Upper Palaeolithic to the Modern period in the central Mediterranean region is likely the result of a progressive decrease in terrestrial mobility as human groups became more sedentary and increasingly reliant on other modes transport over time, as with wider Europe (Holt *et al.*, 2018a). A gradual reduction in lower limb robusticity has been documented throughout the European Pleistocene and Holocene, particularly following the transition to agriculture (Barbieri *et al.*, 2017; Holt, *et al.*, 2018a; Macintosh *et al.*, 2014b; Ruff *et al.*, 2015) and marking the point in time at which widespread sedentism first emerged (Bar-Yosef and Belfer-Cohen, 1989). Declining lower limb robusticity following the transition to agriculture has also been observed in North Africa (Stock *et al.*, 2011) and North America (Bridges, 1989; Bridges *et al.*, 2000; Ruff *et al.*, 1984). The results of this chapter reaffirm that central Mediterranean Neolithic groups had levels of lower limb robusticity similar to that of pre-agricultural groups (Lambert *et al.*, 2013; Marchi, 2008; Marchi *et al.*, 2006, 2011; Ruff *et al.*, 2006a), and establishes that lower limb rigidity gradually declined from the Mesolithic to the Copper Age, before a sharp reduction took place during the Bronze Age.

As was initially reported by Marchi and colleagues in a series of studies on the N. Italian Ligurian sample (2006, 2011; 2008; 2008; see Chapter Three, Section 3.4.1), the timing of marked declines in lower limb robusticity in the central Mediterranean differs to wider Europe. These studies revealed that the Ligurian sample had elevated lower limb robusticity and greater bending rigidities analogous to pre-agricultural groups, related to mobility on rugged terrain associated with pastoralism. Similar results were also reported for Ötzi the Iceman (Ruff *et al.*, 2006a) and Neolithic southern France (Lambert *et al.*, 2013) and further suggested that the characteristic decline in lower limb mobility with the transition to agriculture was not applicable to the central Mediterranean region. The results of these previous studies have been replicated in this chapter, but the extent to which this trend was representative of the wider central Mediterranean Neolithic was previously unknown. Surprisingly, the analysis of S. Italian and Sardinian Neolithic tibiae in this chapter documents elevated lower limb robusticity within these groups as well (see Section 7.5.2 for discussion on spatial trends within the Neolithic).

On considering lower limb robusticity in the central Mediterranean after the Neolithic, Marchi *et al.* (2011) tested Robb's (1994c; Table 7.1) hypothesis that Copper Age groups would exhibit skeletal evidence for high levels of mobility similar to hunter-gatherers. The results of their study instead showed that a sharp decline in mobility took place in the Copper Age, thus refuting Robb's (1994c) model. However, Marchi *et al.*'s (2011) research, in using what material was available at the time, relied on central European Copper Age material that Sládek *et al*. (2006a, 2006b) had demonstrated as having decreased lower limb robusticity. In these studies, Sládek *et el*. (2006a, 2006b) used lower limb CSG properties to investigate differences in terrestrial mobility between earlier Corded Ware and later Bell Beaker groups who were traditionally considered highly mobile pastoralists, determining that there was no marked increase in mobility over time. This chapter re-evaluated Robb's (1994c) hypothesis using comparative material from the central Mediterranean, and also shows that a reduction in lower limb rigidity took place coming into the Copper Age, especially among males. This suggests that central Mediterranean Copper Age societies engaged in less physically intense mobility behaviours than Neolithic societies and that there was a decline in terrestrial mobility in the Copper Age, supporting Marchi *et al.*'s (2011) findings. However, the analysis of long-term trends in TA and I_{max}/I_{min} in the tibia implies that this pattern was part of a larger trend leading to a period of lower limb gracility in the Bronze Age. On balance, the results do not support Robb's (1994c) hypothesis, but do show that the temporal decrease in lower limb robusticity between the Neolithic and Copper Age reported here is much less drastic than that reported by Marchi *et al*. (2011). As Table 7.11 shows, the analysis in this chapter records a 16.48% decrease in average J in the tibia among males, in contrast to 28.8% in Marchi *et al.*'s study (2011) and a 13.73% decrease in average J in the tibia among females compared to 22.83%. These vastly different rates of decline do at least demonstrate the value of re-evaluating Robb's (1994) hypotheses with new data from the central Mediterranean.

Table 7.11: The percent decrease in average J between the Neolithic and Copper Age in 1) this study and 2) Marchi et al. (2011).

CSG property	**% difference**	
	This study	*Marchi* et al. *(2011)**
Males		
Femur *J* (50%)	-16.25	-19.17
Tibia *J* (50%)	-16.48	-28.88
Females		
Femur *J* (50%)	-2.80	-17.10
Tibia *J* (50%)	-13.73	-22.83

*Calculated from the descriptive statistics provided in Tables 13.5, 13.7-13.8 in Marchi *et al*. (2011).

It is important to assess the contribution of these results to the discussion regarding the economy of the central Mediterranean Copper Age. The 4th-3rd millennia BC are traditionally associated with the intensification of pastoralism in the central Mediterranean, which resulted in increased population mobility and a lack of permanent settlement (Cocchi Genick, 2009). In spite of Barker's (1981) critical evaluation of Copper Age economy and society, which suggested the period was defined by mixed agriculture and a progressive development towards specialised pastoralism in the Bronze Age, the 4th-3rd millennia BC are still commonly associated with the widespread intensification of transhumant pastoralism (for overview of debate see Robb, 2007). It is clear that the central Mediterranean Copper Age and Bronze Age samples analysed in this study do not exhibit evidence for extremely high levels of terrestrial mobility comparable to pre-agricultural groups, as was proposed by Robb (1994c). This further confirms that the Copper Age was not a period of increased terrestrial mobility, and further supports the argument that the traditional pastoralist narrative has been over emphasised. However, it is important to note that the Bronze Age comparative sample is restricted to a single site, Olmo di Nogara - a mid-2nd millennium BC necropolis situated on the Po Plain, south of Verona (De Marinis, 1999; Salzani *et al.*, 2016). It is therefore not surprising that the Bronze Age sample has gracile lower limbs and similar cross-sectional traits as the Copper Age Po Valley sample (i.e. low *TA* values, high I_{max}/I_{min} shape indices) (see Section 7.5.2). By comparison, the other time periods analysed in this chapter consist of skeletal material from multiple sites distributed throughout the central Mediterranean and beyond. Therefore, the extent to which the Bronze Age material analysed in this chapter is representative of the mobility behaviours of the central Mediterranean region is uncertain. Future research should to seek examine Bronze Age material from throughout the Italian peninsula, Sicily and Sardinia, but ultimately the results do not support the scenario that the Copper Age was a period of increased terrestrial mobility.

However, it is probable that Copper Age and Bronze Age pastoralism would have been undertaken on a relatively small scale and became increasingly specialised (Barker, 1981, 1999; Skeates, 1997). Therefore, prehistoric pastoralism may not be easily detectable or traceable through skeletal analysis or the biomechanical approach used here (Sparacello *et al*., 2011). As highlighted by Robb (2007), there is some debate over the extent to which pastoralism increased, or displaced traditional farming, in the Copper Age. The recent discoveries of substantially sized settlements, with long-term occupation histories, throughout the Italian peninsula and Sardinia (Anzidei *et al.*, 2007, 2012; Bernabò Brea *et al.*, 2011; Cazzella and Moscoloni, 1999; Fugazzola Delpino *et al.*, 2003; Manfredini, 2014; Manunza *et al.*, 2014; Webster and Webster, 2017) has also begun to challenge many of the long-standing views of the 4th-3rd millennia BC in the regional archaeological literature (Cardarelli, 2015). It is also important to emphasise that the archaeological record of the central Mediterranean Copper Age is extremely variable and cannot be easily branded with monolithic economic, social, ideological and cultural changes. It is likely that there was considerable spatial and temporal variation in when, or even if, such economic and subsistence changes took hold.

7.5.2 Spatial variation in the Neolithic and Copper Age

The analysis of mid-shaft CSG properties of the tibia showed slightly more sample variation than in the femur, but the results contrast to expectation. The elevated lower limb robusticity of the pooled Neolithic sample within the analysis of long-term temporal trends is not surprising, in light of the previous research on the Ligurian sample (Marchi, 2008; Marchi *et al.*, 2006, 2011; discussed in Section 7.61). However, when considering geographic dissimilarities between the individual Neolithic samples, the results contrast with expectations. It was proposed at the beginning of this chapter that the S. Italian Neolithic sample would display more gracile lower limbs than the N. Italian Neolithic sample, owing to differences in subsistence strategy, terrain and settlement patterns between the two regions. The results showed that tibiae of S. Italian Neolithic individuals exhibited slightly higher mean values for all CSG properties than N. Italian Neolithic individuals and indicate that both groups undertook similarly intense mobility behaviours. The Sardinian Neolithic sample also features elevated *TA* and *J* values in the tibia, but there is greater continuity with the Sardinian Copper Age sample.

The results are surprising, as the S. Italian Neolithic sample consists of individuals from sites situated on the large flat coastal expanses of the Tavoliere in Apulia and those surrounding Matera in Basilicata (see Chapter Three, Section 3.6), and is associated with sedentary settlement within nucleated villages (Jones, 1987; Manfredini and Cassano, 2005; Whitehouse, 2013). Furthermore, the S. Italian Neolithic is traditionally associated with mixed agriculture, that entailed intensive cultivation and small scale herding (Natali and Forgia, 2018; Tafuri *et al.*, 2014), in contrast to the pastoral subsistence of the Ligurian N. Italian Neolithic sample (Le Bras-Goude *et al.*, 2006; Pearce, 2013). Therefore, differences in mobility behaviours and lower limb biomechanics were expected between the two regions, with the S. Italians showing evidence for less terrestrial mobility. However, there is evidence to suggest that Neolithic groups in southern Italy may have been highly mobile for a multitude of different reasons, such as maintaining social networks (Robb, 2007) or participation in extensive exchange networks for the distribution of raw materials (Brown and Tykot, 2018; Leighton, 1992; Robb and Farr, 2005) and ceramics (Binder *et al.*, 2018; Malone, 1986) (for an overview see Muntoni, 2012). Strontium isotope analysis of individuals from several sites from across Apulia, including those from Masseria Candelaro analysed here (Chapter Three, Section 3.6), also supports the archaeological evidence that Neolithic S. Italian individuals engaged in long distance terrestrial mobility throughout life.

The slightly higher average I_{max}/I_{min} values observed in S. Italian Neolithic tibiae do indicate increased bending in the antero-posterior plane and unidirectional mobility behaviours within this sample (Shaw and Stock, 2009). This differs from the rounder cross-sections seen in the tibiae of the N. Italian and Sardinian Neolithic samples, where locomotion on the uneven mountainous terrain of their local landscape settings would have resulted in multi-directional lower limb loading and greater medio-lateral strengthening in the lower limbs (Ruff, 2019; Wescott, 2014). Therefore, the spatial variation in mid-shaft cross-section shape in the tibia between the individual Neolithic samples, alongside their greater J values, likely relates to high levels of mobility on different kinds of terrain. On the basis of the small S. Italian sample (n = 9), the results tentatively suggest that the increased lower limb robusticity previously reported for Italian Neolithic groups by Marchi *et al.* (2006, 2011) is not unique to the Ligurian Neolithic, and may also be representative of Neolithic groups elsewhere in the peninsula. Ultimately, further analysis with a larger sample of Neolithic individuals from S. Italy and elsewhere in the Italian peninsula should be undertaken to fully investigate spatial variation in lower limb CSGs throughout the region during this time.

The comparisons of mid-shaft *TA*, *J* and I_{max}/I_{min} in the femur and tibia between the Italian Copper Age and Late Neolithic Maltese samples did reveal some spatial variation although this was not as prominent as might have been expected given their diverse landscape settings. Perhaps most surprising was the lack of any major differences between the Late Neolithic Maltese sample and coeval Copper Age groups from Sardinia and the Italian peninsula. Reduced lower limb loading and terrestrial mobility have been observed in groups from the Andaman Islands (Stock and Pfeiffer, 2001), and it was expected that the Maltese would also exhibit evidence for decreased terrestrial mobility as a result of their geographically restricted island context – the Maltese Islands have a total area of 316 km^2, of which the island of Gozo, where the sample comes from, accounts for only 67 km^2 (Schembri *et al.*, 2009). The results instead suggest that the Late Neolithic community of the Maltese Islands undertook similarly intensive mobility behaviours to contemporary Copper Age groups. However, whilst the Maltese Islands are limited in geographical area, which might be expected to limit the extent of terrestrial mobility and lead to lower limb gracility, the topography of the island chain is very irregular. When the physical landscape of the Maltese Islands is considered, the results are perhaps less surprising and indicate that the Late Neolithic population of Malta were extensively engaging with the irregular and rugged local landscape. The results from Late Neolithic Malta do, however, have implications for how we define the concept of "mobility" in studies using cross-sectional geometry.

Within the Italian peninsula, a recent comparison between the Copper Age Po Valley sample and a sub-set of individuals from the central Italian Copper Age group from Ponte San Pietro (see Chapter Three, Section 3.5.1) reported differences in the biomechanical profiles of the two groups which was attributed to their distinctive landscape contexts (Parkinson *et al.*, 2018). The Copper Age Po Valley sample comes from the flat expanses of the Po Plain, whereas the central Italian sample is associated with the hilly terrain of the Apennines foothills in Tuscany and Marche. The comparisons with a wider set of coeval groups in this chapter further corroborates the results of the previous study, with Copper Age Po Valley tibiae exhibiting the lowest mean values for *TA* and *J* than all other groups. Among the other sites analysed in this chapter, high *TA* and *J* values and significantly rounder tibial cross-section shape in the Neolithic Sardinian and Alpine Beaker samples likely reflects similar adaptations to rugged mountainous terrain - the Alpine Beaker sample coming from Valle d'Aosta in the Italian Alps and the Sardinian Neolithic sample coming from the mountainous region of San Benedetto in Iglesias (see Chapter Three).

Given the lack of pronounced sample variation within the Copper Age, it is also important to critically evaluate the solid CSG method. Although periosteal (external) contours represent the most mechanically relevant bone and are therefore reliable indicators of habitual behaviour (Stock and Shaw, 2007), endosteal (internal) contours also reflect important adaptations to mechanical loading (Ruff and Larsen, 2014; Ruff, 2019). Ruff *et al*. (2006a) found that in addition to increased lower limb rigidity, the Iceman's cortical area (%CA) was high in comparison to the Neolithic Ligurian sample – which is particularly relevant to the interpretation of the Alpine Beaker sample, which comes from a similar environmental context to the Iceman. Whilst capturing endosteal contours is desirable whenever it is possible, solid mid-shaft CSG properties of the femur and tibia have been shown to accurately estimate true CSG properties. Whilst Macintosh *et al.*'s (2013) study was based on a sample of one population, earlier studies comparing true and solid mid-shaft CSG properties have done so using a wider variety of global populations (Sparacello and Pearson, 2010; Stock and Shaw, 2007). If any major differences in lower limb loading were present, it would be likely that they would be reflected in CSG properties other than %CA, and therefore the solid CSG properties reported here can be considered as accurate reflections of lower limb robusticity and loading between the individual samples.

7.6 Conclusion

This chapter examined mid-shaft CSG properties in order to examine changes in mobility behaviour between and within the Neolithic and Copper Age of the central Mediterranean. The results document a reduction in lower limb loading and terrestrial mobility across the ca. 24,000 years represented by this study. Between the Neolithic and Copper Age, there was a decline in lower limb robusticity and terrestrial mobility, although this formed part of a larger trend leading towards a significant reduction in lower limb robusticity in the Bronze Age. The Copper Age sample did not show evidence for high levels of terrestrial mobility akin to pre-agricultural groups, contrary to Robb's (1994c) hypothesis. This further suggests that pastoralism in the central Mediterranean during the 4^{th}-3^{rd} millennia BC was likely to be not so intensive as to result in an overall increase in lower limb loading. The spatial analysis between the individual Neolithic and Copper Age groups tentatively suggests that increased lower limb robusticity and terrestrial mobility were a trait of most central Mediterranean Neolithic societies.

8 CONCLUSION

8.1 Introduction

This thesis has investigated social and economic change in the 4th and 3rd millennia BC in the central Mediterranean by way of a bioarchaeological approach that examined body size and skeletal indicators of habitual behaviour. The study also extended the temporal scope of the analysis to the Upper Palaeolithic to Modern periods and in doing so allowed the results from the Neolithic and Copper Age to be placed within the context of large-scale changes in post-cranial robusticity across the duration of the Late Pleistocene and Holocene. The analysis of body size explored diachronic and synchronic trends in nutritional status, whilst the analysis of upper and lower limb cross-sectional geometry provided insights into patterns of habitual activity and mobility in central Mediterranean prehistory. The results of this study have been interpreted within the context of widely accepted social and economic models that have been proposed for the Neolithic and Copper Age in the central Mediterranean and have offered a contribution to our understanding of prehistoric lifestyles in the central Mediterranean.

In addition, this thesis analysed complex assemblages of commingled and fragmented human remains and it is hoped that this research has underscored the value of such skeletal material and that the approaches adopted here provide a framework for future research. The following chapter summarises the outcomes of the research and discusses their implications for understanding Neolithic and Copper Age society in the central Mediterranean. Finally, the limitations of the study are considered, and future research directions are offered.

8.2 Summary of findings

The results of this study indicate that the Copper Age was characterised by greater diversity in habitual manual behaviours and an overall decline in post-cranial robusticity following the Neolithic. This suggests that there was an overall decrease in the intensity of habitual manual behaviours and a reduction in terrestrial mobility during the Copper Age. Copper Age groups also exhibited decreased sexual dimorphism in upper limb CSG properties, suggesting that patterns of physical activity were not influenced by a culturally constructed sexual division of labour. The results also documented a reduction in body size during the Neolithic, suggesting that the introduction of agriculture was a period of increased physiological stress, but that the Copper Age and Bronze Age saw a subsequent gradual recovery. The findings of the research are summarised in the following sections and in Table 8.1, with reference to the study expectations proposed in Chapter One.

Table 8.1: Summary of the main study findings, research questions and expectations. Expectations are fully outlined in Chapter One and in each relevant results chapter. Green text indicates study expectations that were supported, red text indicates expectations that were not.

Research question	**Expectation**	**Result**
1) *Do body size and nutritional status change in response to economic and social change during the 4th-3rd millennia BC?*	- Decrease in body size during the Neolithic, some evidence for sexual dimorphism in the Metal Ages	- Body size declines in the Neolithic and recovers in the Bronze Age. The recovery is characterised by a divergence in body size between males and females
2) *Do patterns of mechanical loading in the upper limb reflect the intensification and diversification of agriculture during the Copper Age?*	- Increase in upper limb robusticity with the intensification of agriculture, greater variation in habitual behaviour with economic diversification	- Decreased upper limb robusticity in the Copper Age - Greater variation in upper limb CSG properties after the Neolithic reflecting more diverse activities
Is there evidence for greater sexual division of labour among Copper Age groups?	- Evidence for sexual division of labour reflecting development of binary gender ideology	- No evidence for sexual division of labour. Copper Age groups show decreased sexual dimorphism compared to Neolithic and Bronze Age samples
3) *Is there evidence for increased terrestrial mobility among Copper Age groups with the adoption of pastoral agriculture?*	- Greater lower limb robusticity in Copper Age groups reflecting increased terrestrial mobility with the development in pastoralism (As per Robb, 1994)	- Copper Age groups have decreased lower limb robusticity relative to Neolithic and pre-agricultural groups - Bronze Age is period of reduced lower limb robusticity and terrestrial mobility**
Do Neolithic and Copper Age groups exhibit spatial variation in lower limb robusticity?	- Regional differences in lower limb morphology reflecting differences in landscape context etc.	- No pronounced spatial variation in either the Neolithic or Copper Age, Copper Age Po Valley is the exception

**More research on a wider sample of Bronze Age material from across the central Mediterranean is needed to further investigate this trend.

8.2.1 Research Question One – Body size and nutritional status

The analysis of stature and body mass was undertaken to explore what impact the economic and social changes associated with the 4th-3rd millennia BC had on body size and nutritional status (Chapter Five). It was expected that body size would decline during the Neolithic, but subsequently recover during the Metal Ages. It was also proposed that increased sexual dimorphism in body size might occur during prehistory. The analysis revealed that there was an overall decline in body size in both males and females coming into the Neolithic. Interpreted within a life history framework, the decline in body size in the Neolithic indicates that the transition to agriculture in the central Mediterranean resulted in increased physiological stress and growth impairment among early agricultural societies, and reflects the pattern seen throughout Europe (Ehler and Vančata, 2009; Macintosh *et al.*, 2016; Niskanen *et al.*, 2018; Piontek and Vancata, 2012). The subsequent recovery in body size during the Copper Age and Bronze Age was also characterised by a divergence between males and females, with body size among men recovering at a greater rate than women. A similar divergence in body size was documented in Neolithic central-southern Europe by Macintosh *et al.* (2016) and was interpreted as reflecting a gender inequality that negatively impacted on nutritional status among women. The body size trends after the Neolithic in the central Mediterranean could be argued as reflecting a similar process of inequality or differentiation between males and females. However, important physiological differences between the sexes more likely explain the lack of temporal variation in female body size, with several studies showing that males show greater susceptibility to environmental stress (Sparacello *et al.*, 2017b; Stini,1969; Stinson, 1985; Vercellotti *et al.*, 2011). After prehistory, body size declined again during the Roman period, signalling another period of significant physiological stress in response to major social, economic and political change.

Interestingly, the analysis of the upper limb (Chapter Six) showed that women throughout time exhibited greater asymmetry in maximum length of the humerus, but that this was most prominent during the Neolithic and Copper Age. Asymmetry in bone length has been suggested to reflect developmental instability and growth impairment (Albert and Greene, 1999; Lewis, 2017), so the occurrence of this trend during the Neolithic at a time of overall reduced body size is significant, supporting the life history interpretation offered for the stature and body mass data.

8.2.2 Research Question Two – Upper limb robusticity and manual activity

The analysis of upper limb CSG properties set out to explore the impact of social and economic change through patterns of manual physical activity, and to test whether the widely accepted models of social change for the Copper Age central Mediterranean were reflected in bioarchaeological data. It was expected that Copper Age groups would display evidence for a greater variety of manual habitual behaviours and sexual division of labour with the emergence of specialised gender roles, craft specialisation and economic diversification (Table 8.1). Established agricultural groups were also expected to show an increase in upper limb mechanical loading with the intensification of agriculture and labour-intensive food processing tasks.

The analysis of overall trends in upper limb robusticity revealed that the transition to agriculture led to a considerable shift in patterns of manual activity. The increased upper limb robusticity of the Neolithic sample indicates that the introduction of food production initially required intense and strenuous manual labour. With the onset of agriculture, males showed evidence for undertaking lateralised physical activities, which may reflect the involvement of men in extra-domestic food production tasks, such as the use of sickles and scythes, in favour for women showing evidence for bilateral activities, likely related to food processing tasks using bimanual saddle querns. This pattern has been observed in wider Europe (Larsen, 2015; Macintosh *et al.*, 2014a; Sládek *et al.*, 2007, 2016, 2018) and suggests that the initial development of agriculture in the central Mediterranean region required a similar labour regime to that of wider Europe. However, as agriculture developed in the central Mediterranean, patterns of habitual activity began to differ from wider Europe.

Whilst increased upper limb robusticity has been observed in other established agricultural societies in prehistoric Europe and North America (Bridges, 1989; Bridges *et al.*, 2000; but see Larsen, 2015; Holt *et al.*, 2018a), the Copper Age saw a decline in the intensity of habitual manual behaviours, contrary to expectation. The analysis of humeral asymmetry showed that the intensification of agriculture in the central Mediterranean was characterised by a greater range of manual behaviours, rather than an increase in the intensity of physical activities. The evidence for greater *variation* in activity over greater *intensity* in the Copper Age, and also in the Bronze Age, suggests that the need to for intensive manual activity was progressively reduced with developments in food processing technology and economic diversification. However, variability in asymmetry continued to increase following the Copper Age, particularly among females from the Bronze Age onwards. By the Bronze Age, a clearer sexual division of labour was in place and females appear to have become involved in increasingly diverse manual activities. The data from the upper limb suggest that women played an increasingly important role in the development of specialised tasks, such as craft production activities, continued economic diversification or production stages of metal working (Barker, 1999; Bazzanella, 2012; Blake, 2014; Cazzella and Guidi, 2011; Gleba, 2017).

The lack of sexual dimorphism in upper limb CSG properties in the Copper Age, in comparison to the adjacent time periods, was surprising. Although there were underlying differences in asymmetry between Copper Age males and females, with males showing greater mean right biased asymmetry, there was considerable overlap in variation in asymmetry between the sexes. These results suggest that there was no pronounced sexual division of labour in the Copper Age and do not support the widely accepted social models that have been developed for the period that proposed that binary gender roles closely aligned to biological sex first emerged in the 4^{th}-3^{rd} millennia BC. Within the Neolithic and Copper Age, there was limited spatial variation in upper limb CSG properties and patterns of manual physical activity within the central Mediterranean.

8.2.3 Research Question Three – Lower limb robusticity and mobility

The analysis of lower limb CSG properties was undertaken primarily to test whether there was a change in mobility behaviour between the Neolithic and Copper Age, and whether Copper Age groups displayed evidence for high terrestrial mobility, following Robb's model (1994c) (Table 8.1). Lower limb CSG properties were also used to explore regional variation in mobility behaviours and adaptations to specific landscape contexts in during the Neolithic and Copper Age. The results corroborated the findings of previous studies demonstrating that the central Mediterranean Neolithic was not characterised by the reduction in mobility and lower limb robusticity that is usually associated with the transition to agriculture (Lambert *et al.*, 2013; Marchi and Sparacello, 2013; Marchi *et al.*, 2006, 2011; Ruff *et al.*, 2006a; Sparacello and Marchi, 2008). Contrary to expectation, the analysis of lower limb CSG properties found that this trend could be extended to S. Italian and Sardinian Neolithic groups, suggesting elevated lower limb robusticity was characteristic of the entire central Mediterranean region.

The analysis of temporal variation between the Neolithic and Copper Age documented a reduction in femoral and tibial rigidity, indicating that human groups were less terrestrially mobile during the 4^{th}-3^{rd} millennia BC. Although not supporting Robb's (1994c) model of skeletal change in Italian prehistory, the magnitude of the reduction in lower limb rigidity observed in this study is much less than that reported by Marchi *et al.* (2011). The economy of the central Mediterranean Copper Age is still often discussed with reference to an increase in pastoralism and population mobility (Cocchi Genick, 2009; Robb, 1994c, 2007), despite Barker's (1981) critique. The results of this thesis provide further evidence that Copper Age groups in the central Mediterranean were not characterised by high levels of terrestrial mobility, and that Copper Age transhumance was likely undertaken on such a small scale that it did not result in an overall increase in lower limb robusticity. This scenario supports Barker's (1981, 1999) view of Copper Age economy as being defined by mixed farming, that featured small-scale herding systems, leading to the development of specialised pastoralism in the later Metal Ages and mirrors Sparacello *et al.*'s (2011) analysis of Iron Age central Italian pastoralists. Contrary to expectation, the focused analysis of the individual Late Neolithic and Copper Age samples from Malta, Sardinia and the Italian peninsula found no significant spatial variation in lower limb CSG properties. Unexpectedly, there was no difference in lower limb morphology between the Late Neolithic Maltese and Alpine Beakers, despite their vastly different landscape contexts.

The Bronze Age saw a further reduction in femoral and tibial rigidity, suggesting the period was one of overall reduced terrestrial mobility, further contesting Robb's (1994c) model. However, the results from the Bronze Age must be considered as preliminary, given that the time period was only represented by one site in this study. Future research should therefore be aimed towards gathering directly comparable solid CSG data for the Bronze Age from throughout the central Mediterranean region.

8.3 Implications of the research

The results of this thesis demonstrate the effectiveness of a bioarchaeological approach in exploring social and economic change in prehistory. Whilst this thesis presents only one body of evidence, bioarchaeology has the unique capacity to provide direct insights into individual lived experiences and past lifestyles. This research has been able to offer a robust investigation of the dominant economic and social themes that are central to the prehistory of the central Mediterranean, integrating the bioarchaeological data with archaeological evidence and a critical evaluation of the archaeological models that have been proposed for the Neolithic and Copper Age. Furthermore, this project has provided important insights into the central Mediterranean Copper Age, which remains a neglected period of study.

Falling between the Neolithic and the Bronze and Iron Ages, the Copper Age forms a crucial juncture between the first agricultural societies and the emergence of widespread social and political complexity that ultimately led to modern western society. The Neolithic and later Bronze and Iron Age time periods have previously been the subject of extensive bioarchaeological research utilising the biomechanical methods used in this study (Holt *et al.*, 2018b; Macintosh *et al.*, 2014a, 2014b; Marchi *et al.*, 2006, 2011; Sparacello and Marchi, 2008; Sparacello *et al.*, 2011, 2015). This thesis sought to comprehensively examine the crucial interim period of the Copper Age in order to establish the manner in which these social and economic changes developed and impacted on the human body. The analysis of body size and long bone cross-sectional geometry revealed surprising results that were contrary to expectation and identified skeletal changes that were unique to the Copper Age (Table 8.1), marking the period as an important chapter in the prehistory of the central Mediterranean.

Perhaps most noteworthy was the lack of sexual dimorphism in cross-sectional properties of the humerus during the Copper Age, relative to the Neolithic and Bronze Age. This does not reflect the widely accepted models of social change that have been proposed for the central Mediterranean Copper Age that argue for the emergence of binary gender roles closely aligned to biological sex during the 4^{th}-3^{rd} millennia BC (Robb, 1994b, 1994c, 2007; Whitehouse, 1992, 2001). Moreover, the results did not support Robb's (1994c) suggestion that Copper Age groups would display evidence for greater sexual dimorphism. Whilst the divergence in body size between men and women during the Copper Age and Bronze Age may indicate that some form of social differentiation between the sexes emerged during the 4^{th} and 3^{rd} millennia BC, Robb and Harris (2018) also point out that most societies have some distinction between males and females. Instead, the trends in body size during the Copper Age are likely reflective of physiological differences between the sexes, rather than a result of social change. However, the lack of sexual dimorphism in upper limb CSG properties during the Copper Age is significant in that it suggests that the division of labour in the Copper Age was not dictated by any ingrained or explicitly expressed binary gender ideology, in comparison to the Bronze Age (this study) or Iron Age (Sparacello *et al.*, 2011). Instead, the biomechanical evidence presented here suggests that a clear sexual division of labour, and by extension binary gender roles, first emerged during the Bronze Age. The brief critical re-examination of the material record for the Copper Age in Chapter Six further supported this interpretation, by highlighting that the models of social change that have been proposed for the 4^{th}-3^{rd} millennia BC in the central Mediterranean have been developed on a fragmentary body of material evidence. In contrast to the widely accepted social models that have been proposed for the central Mediterranean Copper Age, it is the point of view of the author that the proliferation of communal burial (i.e. complex secondary burial rites) and transformations in visual culture (i.e. increasingly schematic representations of human form) during the 4^{th}-3^{rd} millennia BC seems to indicate an overarching shift away from emphasis on the individual, and a move towards a communal or collective identity. Rather than reflecting a precursor to the emergence of gender roles that eventually took hold in the Bronze Age, the Copper Age also bears evidence for other important social and ideological processes.

Another important outcome of this research was the investigation of Copper Age mobility behaviours. Previous studies had documented that Neolithic groups in Liguria (Marchi *et al.*, 2006) and southern France (Lambert *et al.*, 2013) did not display a typical reduction in lower limb robusticity (Holt *et al.*, 2018b; Macintosh *et al.*, 2014b; Ruff *et al.*, 2015). However, the extent to which this trend persisted into the Holocene was unknown. The analysis of Neolithic groups in southern Italy and Sardinia as part of this study suggested that increased terrestrial mobility was typical of the central Mediterranean during this period. Testing Robb's (1994c) hypothesis that Copper Age groups would also show evidence for increased terrestrial mobility, the results of this thesis indicate that there was a significant reduction in lower limb robusticity and an overall decline in terrestrial mobility in the 4^{th}-3^{rd} millennia BC. This result provides further evidence that the Copper Age was not a period of increased terrestrial mobility, and that the traditional "nomadic pastoralist" narrative has been historically over emphasised (see Barker, 1981; Manfredini, 2014).

This thesis also incorporated published comparative data, demonstrating the importance of utilising and continually building upon existing archaeological datasets. The integration of comparative material from the Ruff (2018c) European database enabled the Neolithic and Copper Age data to be placed within the context of largescale trends in body size and post-cranial robusticity across the *longue durée* of the European Late Pleistocene and Holocene. In most cases, the significance of the Neolithic and Copper Age data only emerged through comparisons with adjacent time periods, whilst data from later time periods enabled more confident interpretations of trends in prehistory. This was particularly the case for the transition from the Mesolithic to the Neolithic and the transition from the Copper Age to the Bronze Age. For example, the long-term divergence in body size between males and females following the onset of the Copper Age was only made apparent through the inclusion of Mesolithic and Bronze Age comparative data. The primary data collected as part of this study have also made a significant contribution to the existing Ruff (2018c) European database. Within Ruff's (2018c) volume, Holt *et al.*'s (2018b) focused study on body size and long bone cross-sectional geometry in France and Italy from the Palaeolithic to Modern periods presents a comprehensive database of pre-agricultural and post-Bronze Age individuals, although was lacking in Neolithic and Copper Age skeletal material. This PhD project has been able to provide an important supplement to this existing database and demonstrate that the central Mediterranean Neolithic and Copper Age were characterised by important, and sometimes unique, skeletal changes.

Furthermore, the interpretation of trends in post-cranial robusticity and body size in prehistory was greatly enhanced and strengthened through comparisons with later time periods, where the socio-economic circumstances affecting nutritional status and regimes of physical activity are better resolved. The analysis of stature, body mass and long bone CSG properties showed that the Roman period was also a time of reduced body size, but increased post-cranial robusticity, similar to the Neolithic. It was not within the scope of this study to fully consider the trends in long bone morphology and body size after prehistory, which have been comprehensively examined by Holt *et al*. (2018b). However, the comparable responses to social and economic change between the Neolithic and Roman period are significant for our understanding of prehistory. The parallels between these two periods suggests that within the ca. 24,000 year represented by the comparative analysis in this study, the Roman and Neolithic periods were the two most profound episodes of skeletal change in the central Mediterranean. The Neolithic and Roman periods can be considered as two of the most important episodes of social and economic transformation in recent human history. Both the Neolithic and Roman periods, the first the development of food processing, the second the emergence of widespread political complexity and established urbanism, stand as markers of irreversible change in the human story that impacted strongly on the human body and the individuals that experienced them.

8.4 Limitations and future directions

This research programme has also identified important areas for future research and highlighted wider issues with the study of the Copper Age in the central Mediterranean. For so long the central Mediterranean Copper Age was considered as a brief horizon of cultural, economic and technological experimentation and instability between the Neolithic and Bronze Age (Puglisi, 1959; Trump, 1966; see Barker, 1981) – in other words, it was viewed as a period of passing transition between two episodes of immense importance. Elements of this interpretative framework have remained intact in mainstream scholarship today, with the Copper Age having been almost always explored and theorised as either a footnote to the Neolithic or a prelude to the Bronze Age. Such an approach runs the risk of conflating the cultural histories of these distinct time periods, and there is a need for future research on the central Mediterranean Copper Age to divorce itself from this paradigm. In this vein, future post-doctoral research will revisit the seminal work of Anglo-American (Robb, 1994b, 1994c, 2007, 2009; Whitehouse, 1992, 2001) and Italian scholars (Cocchi Genick, 2004; Cazzella and Guidi, 2011; Dolfini, 2006a, 2006b) who have theorised social and ideological change in central Mediterranean prehistory, and provide a much needed critical assessment of their work in light of the recent developments in our understanding of the chronology, settlement and mortuary records for the Copper Age.

This research also employed novel methods in the analysis of commingled and fragmented human remains and it is hoped that the methodological approach of this study provides a framework for future research. Chapter Four offered a conceptual discussion on the issues faced by many bioarchaeologists that work with commingled human remains, whilst the individual results chapters acted as specific case studies for how such challenges can be overcome. This research also emphasises the impact of recent developments in archaeological science on the study of such challenging skeletal material. Methods in archaeological science can return maximum results from efficient and minimal sampling procedures, thus bringing new life to disarticulated human remains, and it is in this vein that this study was undertaken. The application of 3D scanning technology has had an enormously beneficial impact on this study, facilitating the adoption of novel methodologies and continued access to the skeletal material long after fieldwork. The ability to continuously work with and revisit study materials, albeit in virtual form, enabled a flexible approach whereby methodologies could be continually refined and reapplied throughout the data processing stage. The analysis of the commingled and fragmentary human remains used in this study owes a great deal to forensic anthropology and palaeoanthropology, where such issues are routinely encountered, but methods are rarely developed for specific archaeological applications. Future research should extend these approaches to other prehistoric contexts where the funerary record is also represented by communal and commingled burial. However, further methodological and experimental studies should also focus on refining and developing the techniques that have been used in this study, particularly by undertaking extensive inter and intra-observer studies.

One of the methodological limitations of this study was that the analysis of long-term trends beyond the Neolithic and Copper Age required comparisons with true CSG properties. The decision was made not to convert solid CSG properties to true CSG properties or convert *SMAs* to *Section Moduli*, and instead comparisons were made using directly comparable properties, or those that are highly correlated between methods. Whilst comparison between solid and true CSG data may be not ideal, the results of Chapters Six and Seven offer an important step towards exploring broad changes in manual activity and mobility behaviours in the central Mediterranean and have identified trends that can be explored through future research using directly comparable solid CSG data.

As highlighted in Chapter Seven, there is a particular need to undertake more comprehensive solid CSG comparisons with central Mediterranean Bronze Age groups, but also pre-Roman Iron age groups, such as those analysed by Sparacello *et al.* (2011, 2015). Further analysis of existing Bronze Age skeletal material from Sardinia (Germanà, 1995; Sanna, 2006; Sarigu *et al.*, 2016) and Sicily (Becker, 1996) would enable a broader regional perspective on manual activity and mobility behaviours during 2nd-1st millennia BC in the central Mediterranean, akin to what has been achieved for the Copper Age in this study. The analysis of spatial variation within the Neolithic also documented increased lower limb robusticity among Neolithic southern Italians, extending the findings of Marchi *et al.*'s (2006) initial work on Ligurian Neolithic group to the wider central Mediterranean. However, patterns of regional variation in lower limb morphology within the Neolithic requires further exploration, and future research should seek to analyse a larger sample of southern Italian individuals, as well as other Neolithic groups from across central-northern Italy and southern Europe. The incorporation of existing long bone cross-sectional data from more recently discovered individuals in southern Italy (Barbieri *et al.*, 2017), along with analysis of the many known Neolithic burials in the Po (Bernabò Brea *et al.*, 2010) and Aosta (Corrain, 1986; Mezzena, 1997) valleys are important resources for future investigations of this trend. For the Copper Age, the many extensive necropolises of the *Gaudo* culture, such as Eboli (Bailo Modesti and Salerno, 1995), Pontecagnano (Bailo Modesti and Salerno, 1998) and Paestum (Aurino, 2015), as well as the recent important discoveries of more cemeteries on the Po Valley (Miari and Benazzi, 2018) and in southern Rome (Anzidei *et al.*, 2003, 2011, 2016), which have begun to fundamentally transform our understanding of the Copper Age, will undoubtedly provide an important resource for future bioarchaeological research.

In an interview discussing his life's work on Italian later prehistory, Lawrence Barfield remarked on the importance for international scholars to engage with the current debates in mainstream Italian scholarship (Pearce and Barfield, 2008). It is hoped that this thesis has adequately engaged with the key themes and debates in the regional archaeological literature, whilst also looking to beyond the central Mediterranean in order to frame the results within the context of wider Europe. However, it is also hoped that this thesis has presented a robust critical evaluation of the established discourses on the later prehistory of the central Mediterranean, challenging the way in which the Copper Age has been studied and theorised, and in doing so providing a stimulus for future research.

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APPENDICES

APPENDIX A

Table A.1: MNI and element frequencies for each skeletal assemblage.

No.	Site	Sample	Long.*	Lat.*	Humeri	Femora	Tibiae
1	Saint-Martin-de-Corléans	Alpine Beaker	7.30	45.74	27	13	13
2	Arene Candide	Neolithic N. Italy	8.33	44.16	16	5	4
3	Arma dell'Aquila[ac]	Neolithic N. Italy	8.33	44.16	6	4	5
4	Grotta Pollera	Neolithic N. Italy	8.33	44.16	22	9	10
5	Bergeggi	Neolithic N. Italy	8.33	44.16	8	5	5
6	Pian del Ciliegio	Neolithic N. Italy	8.33	44.16	2	1	1
7	Forlì-Celletta	Copper Age Po Valley	12.01	44.22	12	8	5
8	Fontenoce-Recanati	Copper Age c. Italy	13.51	43.36	27	13	13
9	Ponte San Pietro[c]	Copper Age c. Italy	11.76	42.54	28	16	17
10	Masseria Candelaro[b]	Neolithic S. Italy	15.82	41.54	8	1	4
11	Fonteviva[b]	Neolithic S. Italy	16.62	40.98		1	
12	Ripa Tetta[b]	Neolithic S. Italy	15.33	41.50		2	
13	Trasano[b]	Neolithic S. Italy	16.64	40.67	9	2	5
14	Samari[b]	Neolithic S. Italy	18.02	40.02		3	
15	San Benedetto-Iglesias	Neolithic Sardinia	8.53	39.36	17	15	15
16	Sacaba'e Arriu	Copper Age Sardinia	8.89	39.67	24	30	27
17	Xagħra hypogeum	Late Neolithic Malta	14.26	36.05	32	31	27

[a]Number of articulated individuals.

[b]Samples had femora that could be reconstructed for length but could not used for analysis of CSG.

[c] *Commingling and disarticulated elements included in sample. Number of individuals may not*

**All Ligurian sites are given coordinates for Arene Candide for purposes of Figure 2.3.*

Table A.2: Additional published radiocarbon dates for all assemblages.

Site	**Sample ID**	**Lab code**	**^{14}C Age (BP)**	**Cal. BC. (95.4%)***	**Reference**
San Benedetto		AA78327	5079 ± 58	3980-3713	Lai, 2009
San Benedetto		AA78328	5044 ± 58	3961-3709	Lai, 2009
San Benedetto		AA78330	4984 ± 52	3942-3655	Lai, 2009
San Benedetto		AA64829	4920 ± 70	3942-3533	Floris, 2001
San Benedetto		AA78329	4969 ± 52	3941-3647	Lai, 2009
Forlì	Tomb 75	?	4466 ± 40	3347-3018	Miari 2014
Xagħra	1268_Spit1_E99/N110.5	OxA-27833	4219 ± 26	2901-2700	Malone *et al*. 2019
Xagħra	799_E107/N114	OxA-3571	4080 ± 65	2871-2476	Malone *et al*. 2009
Xagħra	1241_E108/N104	OxA-33928	4096 ± 36	2866-2497	Malone *et al*. 2019
Xagħra	1206_Spit4_E98/N109	OxA-27832	4077 ± 33	2859-2491	Malone *et al*. 2019
Xagħra	1241_E108/N104	OxA-33927	4050 ± 36	2840-2473	Malone *et al*. 2019
Xagħra	1206_Spit4_E100/N109	OxA-33926	4040 ± 35	2835-2472	Malone *et al*. 2019
Xagħra	1206_E100/N109	SUERC-438	4035 ± 35	2834-2471	Malone *et al*. 2009
Scab'e Arriu	Monte Claro context	AA64829	3989 ± 41	2621-2436	Lai, 2009
Xagħra	960_E101.5/N110	OxA-27803	4027 ± 26	2619-2474	Malone *et al.* 2019
Xagħra	1241_Spit1_E108/N104	OxA-27838	3958 ± 24	2569-2349	Malone *et al*. 2019
Xagħra	1268_Spit2_E99/N110	SUERC-453	3920 ± 45	2566-2236	Malone *et al*. 2019
Xagħra	960_Spit1_E101.5/N110	SUERC-439	3910 ± 40	2550-2234	Malone *et al*. 2009
Xagħra	1241_Spit1_E108/N104	SUERC-439	3920 ± 35	2547-2293	Malone *et al*. 2009
Xagħra	960_Spit3_E101.5/N110	SUERC-453	3901 ± 45	2546-2209	Malone *et al*. 2019
Xagħra	799_E107/N114	SUERC-453	3889 ± 45	2476-2207	Malone *et al*. 2019
Xagħra	1206_Spit1_E99/N109	SUERC-453	3862 ± 45	2466-2205	Malone *et al*. 2019

**Calibrated using OxCal v4.3.2 (Bronk Ramsey, 2017) and IntCal13 (Reimer et al., 2013)*

Table A.3: List of articulated individuals in the N. Italian sample.

N. Italian	Sex	Left Humerus	Right Humerus	Femur	Tibia
Arene Candide VII B.Brea	?	X	X	X	X
Arene Candide 1 Tinè	M	X	X	X	X
Pian del Ciliegio 1	M	X	X	X	X
Arene Candide 8PE	M	X	X	X	X
Arene Candide 7PE	M	X	X	X	X
Grotta della Pollera 13PE	M	X	X	X	X
Grotta della Pollera 10PE	M	X	X	X	X
Grotta della Pollera 12PE	F	X	X	X	X
Grotta della Pollera 6246PE	M	X	X	X	X
Grotta della Pollera 30PE	M	X	X	X	X
Grotta della Pollera 14PE	F	X	X	X	X
Grotta della Pollera 33PE	F	X	X	X	X
Arma dell'Aquila 1 (R V)	F	X	X	X	X
Grotta della Pollera 1 Tinè	F	X	X	X	X
Arene Candide XII	F	X	X	X	
Arma dell'Aquila 2	M	X	X	X	X
Bergeggi 2PE	M	X	X	X	X
Bergeggi 3PE	M	X	X	X	X
Bergeggi 5PE	F			X	X
Grotta della Pollera 32PE	M	X		X	X
Bergeggi 4PE	M	X	X	X	X
Arma dell'Aquila III (R2)	M			X	X
Bergeggi 1	M	X	X	X	X
Arene Candide IXFI	M				X
Grotta della Pollera 34Issel	M	X	X		X
Grotta della Pollera 101A	?	X			
Arma dell'Aquila V	F	X			
Arene Candide 2 Tinè	M	X	X		X
Grotta della Pollera 22PE	M	X	X		
Arene Candide II B.Brea	?	X	X		
Arene Candide III B.Brea	?	X	X		X

Table A.4: List of articulated individuals in the Copper Age Po Valley assemblage.

Copper Age Po Valley	Sex	Left Humerus	Right Humerus	Femur	Tibia
Forlí-Celletta _T25	M	X		X	
Forlí-Celletta _T27	F		X		
Forlí-Celletta_T13	M			X	X
Forlí-Celletta _T60	M	X	X	X	
Forlí-Celletta _T2	M	X	X	X	X
Forlí-Celletta _T6	?	X			
Forlí-Celletta _T40	M		X	X	X
Forlí-Celletta _T26	M		X		
Forlí-Celletta _T7	M		X		
Forlí-Celletta _T42	M	X	X	X	X
Forlí-Celletta _T47	M			X	X
Forlí-Celletta _T72	?			X	

Table A.5: List of articulated individuals in the Ponte San Pietro assemblage.

Individual	Sex	Left Humerus	Right Humerus	Femur	Tibia
Ponte S. Pietro _6407/1	M	X		X	X
Ponte S. Pietro _6408/1	F	X	X	X	X
Ponte S. Pietro _6409	M	X	X	X	X
Ponte S. Pietro _6410	M	X	X	X	X
Ponte S. Pietro _6411	F	X		X	X
Ponte S. Pietro _6413	M	X	X		
Ponte S. Pietro _6414	F	X	X	X	X
Ponte S. Pietro _6416	M	X	X	X	X
Ponte S. Pietro _6417	F	X	X	X	X
Ponte S. Pietro _6418	M	X	X	X	X
Ponte S. Pietro _6419	M	X	X	X	X
Ponte S. Pietro _6420	F	X	X	X	X
Ponte S. Pietro _6429	F	X		X	
Ponte S. Pietro _6430	F	X	X	X	X
Ponte S. Pietro _6412	M			X	X
Ponte S. Pietro _6422	F			X	X
Ponte S. Pietro _11.b	M	X	X	X	X
Ponte S. Pietro _14ac	F	X	X		
Ponte S. Pietro _15ac	M	X	X	X	
Ponte S. Pietro _11a	M	X		X	X

Table A.6: List of articulated individuals in the Fontenoce-Recanati assemblage.

Individual	Sex	Left Humerus	Right Humerus	Femur	Tibia
Fontenoce _8.1	M	X	X	X	X
Fontenoce _10.1	F	X	X		
Fontenoce _12.1	M	X	X	X	X
Fontenoce _12.2	F	X	X	X	X
Fontenoce _11.1	F	X	X	X	X
Fontenoce _14.1	M	X	X	X	X
Fontenoce _15.1	F	X	X	X	X
Fontenoce _16.1	M	X	X	X	X
Fontenoce _20.1	F	X	X	X	X
Fontenoce _20.2	F	X	X	X	X
Fontenoce _18.1	M	X	X	X	X
Fontenoce _21.1	M	X	X	X	X
Fontenoce _3.6	M		X	X	X
Fontenoce _1.1	F		X		X
Fontenoce _19	M		X		
Fontenoce _19.1	M			X	

Table A.7: List of articulated individuals in the S. Italian sample used in the analysis of cross-sectional geometry.

S. Italian	Sex	Left Humerus	Right Humerus	Femur	Tibia
Trasano _Cantiere Sud C	F	X	X		X
Trasano _Silo 9	F	X	X		X
Trasano _1	M	X	X		X
Trasano _Silo 12	M	X			X
Trasano _TS2	F	X	X		X
Masseria Candelaro _Sep. Mista 1	M	X	X		X
Masseria Candelaro _Sep. Mista 2	M	X	X		
Masseria Candelaro _Sep. Est 3	M		X		X
Masseria Candelaro _4 - Tomb 3	M	X	X		X
Masseria Candelaro _8	F		X		X

Table A.8: List of sites isolated from the Ruff (2018c) European database.

No.*	Name	Time period	Region	Long.	Lat.	Males	Females	Total
1	Cro-Magnon	UP	S. France	4.3	49.4	2	1	3
2	Cap Blanc	UP	S. France	1.1	46.0		1	1
3	Chancelade	UP	S. France	0.6	46.0	1		1
4	Saint Germain-la-Rivièr	UP	SW. France	0.2	44.9		1	1
5	Rochereil	UP	S. France	0.6	45.7	1		1
6	La Rochette	UP	France	1.1	45.0	1		1
7	Le Peyrat	UP	France	1.1	45.2		1	1
8	Cuzoul de Gramat	Mesolithic	France	1.7	44.8	1		1
9	Culoz	Mesolithic	France	5.8	46.1	2		2
10	Le Rastel	Mesolithic	S. France	7.4	43.8	1		1
11	Birsmatten	Mesolithic	Switzerland	7.5	47.4		1	1
12	Grotte des Enfants	UP	Italy	7.6	43.8	1	2	3
13	Barma Grande	UP	NW Italy	7.6	43.8		1	1
13	Arene Candide	UP	NW Italy	8.3	44.2	4		4
14	Caviglione	UP	NW Italy	7.6	43.8		1	1
15	Sassari	Modern	Sardinia	8.8	40.8	5	5	10
16	Bonifacio	Mesolithic	Corsica	9.2	41.4		1	1
17	Riparo Tagliente	UP	Italy	11.0	45.6	1		1
18	Roselle	Medieval	C. Italy	11.1	42.8	12	10	22
19	Olmo di Nogara	Bronze Age	N Italy	11.1	45.2	17	16	33
20	Vatte di Zambana	Mesolithic	Italy	11.1	46.2		1	1
21	Piazza della Signoria	Medieval	C. Italy	11.3	44.1	6	8	14
22	Villabruna	UP	N. Italy	11.5	46.1	1		1
23	Mondeval	Mesolithic	Italy	12.2	46.5	1		1
24	Lucus Feroniae	Roman	SW Italy	12.6	42.1	11	15	26
25	Uzzo	Mesolithic	Sicily	12.7	38.2	3		3
26	Molara	Mesolithic	Italy	13.3	38.1	1		1
27	Riparo Continenza	UP	C. Italy	13.5	42.0	1		1
28	Paglicci	UP	UP	13.6	41.7		2	2
29	Vicenne Campochiaro	Medieval	S. Italy	14.5	41.5	11	7	18
30	San Teodoro	UP	S. Italy	14.6	38.0		2	2
31	Quadrella	Roman	Italy	14.6	41.0	12	7	19
32	Siracusani	Modern	Sicily	15.3	37.1	17	6	23
33	Romito	UP	S. Italy	15.9	39.9	1		1
34	Ostuni	UP	S. Italy	17.5	40.7	1		1
35	Parabita (Veneri)	UP	Italy	18.1	40.1	1		1
36	Romanelli	UP	Italy	18.4	40.0	1		1
37	Schela Cladovei	Mesolithic	Romania	22.1	46.3	12	5	17

*Numbers correspond to Figure 3.3, Chapter 3.

UP = Upper Palaeolithic

Table A.9: List of Copper Age that sites were actively considered for study.

Site	Region	Phase	Size	Description	Status	Additional comments/Reason not studied
Laterza	Apulia	CA	Large	Dentition only	Availble for study	Not suitable
Eboli	Campania	CA	Large	Fragmentation, commingled	Availble for study	Beyond scope of this study
Paestum/Gaudo	Campania	CA	Very large	Commingled	Not availble for study	Permission revoked by Sop. Napoli/Paestum upon arrival
Mirabella Elcano	Campania	CA	Small/Medium	Articulated/commingled	Unknown	Old excavation - Remains may not survive
Pontecagnano	Campania	CA	Medium	Poor preservation, concretion	Availble for study	Fieldwork curtailment - Host professor was seriously injured in road accident
Chiusa d'Ermini	Latium	CA	Small	Poor preservation, fragmentary	Availble for study	Poor preservation
Selvicciola	Latium	CA	Very large	Poor preservation, concretion	Availble for study	Beyond scope of this study
Torre della Chiesaccia	Latium	CA	Large	Articulated/commingled /concretion?	Not availble for study	Remains under active study at the time of writing
Ponte delle Sette Miglia	Latium	CA	Large	Articulated/commingled /concretion?	Not availble for study	Remains under active study at the time of writing
Romanana	Latium	CA	Large	Articulated/commingled /concretion?	Not availble for study	Remains under active study at the time of writing
Garavicchio	Tuscany	CA	Small	Poor preservation, fragmentary	Availble for study	Poor preservation
La Porcareccia	Tuscany	CA	Small	Poor preservation, fragmentary	Availble for study	Poor preservation
Grotta La Tana	Tuscany	CA	Small	Poor preservation, fragmentary	Availble for study	Poor preservation
Grotti di Equi	Tuscany	CA	Small	Poor preservation, fragmentary	Availble for study	Poor preservation
La Pianannce	Tuscany	CA	Small	Poor preservation, fragmentary	Availble for study	Poor preservation
Colle Val d'Elsa	Tuscany	CA	Small	Commingled/articulated ?	Not availble for study	Not available for study at time of research
Grotta Spinosa	Tuscany	CA	Large	Commingled	Availble for study	Poor preservation
Spilamberto	Emilia-Romagna	CA	?	Articulated individuals	Unknown	Location unknown
Gattolino di Cesena	Emilia-Romagna	CA	Very small		Unknown	Likely poor preservation
Bologna Airport	Emilia-Romagna	CA	Small	Articulated individuals	Unknown	Likely poor preservation

Table A.9 cont.

Site	Region	Phase	Size	Description	Status	Additional comments/Reason not studied
Remedello	Lombardy	CA	Small	Articulated individuals	Availble for study	Remains could not be removed from display boxes
Ligurian Caves	Liguria	CA		Commingled	Availble for study	Numerous sites analysed, but excluded due to preservation
Piano Vento	Sicily	ECA	Medium	Commingled	Not availble for study	Collection was eventually traced, but beyond scope of this study
Roccazzello	Sicily	LCA	Medium/Small?	Commingled	Not availble for study	Likely that level of preservation was not suitable
Pitrazzi	Sicily	LCA	Medium/Small	Commingled	Availble for study	Beyond scope of this study
Grotta del Vecchiuzzo	Sicily	CA	?	Commingled	Unknown	Cannot be traced
Grotta della Chiusilla	Sicily	CA	?	Commingled	Unknown	Cannot be traced
Grotta del Fico	Sicily	CA	?	Commingled	Unknown	Cannot be traced
Scintillia	Sicily	CA	Small	Articulated/commingled	Not availble for study	Fieldwork curtailment - Numerous failed attempts made to visit and analyse material
Santa Caterina Pittinuri	Sardinia	CA	Large	Commingled, fragmented	Availble for study	Not available for study at the time of research
Montessu	Sardinia	CA	?		Availble for study	
Cannas di Sotto T. 12	Sardinia	CA	Large	Commingled, fragmented	Availble for study	Analysed, but excluded due to preservation
Serra Cannigas	Sardinia	CA	?		Unknown	
Mind'e Gureu	Sardinia	CA	?	Fragmentation, commingled	Unknown	
Bonuighinu	Sardinia	LN	Small	Commingled?	Unknown	
Serra Crabiles t.4	Sardinia	LN	Small	Commingled?	Unknown	
Grutta de Longu Fresu	Sardinia	LN	Small	Commingled?	Unknown	
Santa Lucia	Sardinia	LN	Small	Commingled?	Unknown	
Masone Perdu	Sardinia	CA	Small	Articulated	Unknown	
Corte Noa	Sardinia	CA	Small	Commingled	Availble for study	Poor preservation
Filigosa T. 1	Sardinia	CA	Small/Medium	?	Unknown	
Mind'e Gureu	Sardinia	CA	Small	Commingled	Availble for study	Poor preservation
Serra Cannigas	Sardinia	CA	Small	Commingled?	Availble for study	Poor preservation
Corti Beccia	Sardinia	CA	Small	Commingled	Availble for study	Poor preservation
Perda Lada, t.3	Sardinia	CA	Small	Commingled	Unknown	

Table A.9 cont.

Site	Region	Phase	Size	Description	Status	Additional comments/Reason not studied
Su Coddu	Sardinia	CA	?	Commingled?	Unknown	
Padru Jossu	Sardinia	CA	Large	Commingled	Availble for study	Bell Beaker, beyond the scope of this study
Xaghra hypogeum tomb	Malta	LN	Large	Poor preservation, concretion	Availble for study	Analysed, but excluded due to preservation
Xemxija	Malta	LN	Large	Poor preservation, fragmentary	Availble for study	Analysed, but excluded due to preservation
Kercem	Malta	LN	Small	Articulated/commingled	Not availble for study	
Buquana	Malta	LN	Small	Commingled, fragmented	Exist	Not available for study at time of research
Ta Trapna	Malta	LN	Small	Commingled, fragmented	Exist	Not available for study at time of research
Santa Lucija hypogeum	Malta		?	Commingled	Exist	Remains were untraceable in 2016 - has since been rediscovered

*Information for Sardinia pers. comm. Dr. Luca Lai, 2016. 'Beyond the scope of this study' referes to collections where permission to study was eventually granted, but undertaking analysis would have involved substantial delay to the research.

APPENDIX B

Table B.1: Results of one-way ANOVA Hochberg GT2 post-hoc comparisons for stature (cm) and body mass (kg) (summarised in Table 5.2).

Time period	*UP S. Europe*	*Mesolithic S. Europe*	*Neolithic*	*Copper Age*	*Bronze Age*	*Roman*	*Medieval*	*Modern*
				Stature				
UP S. Europe		1.000	<0.001	0.035	0.84	0.079	1.000	0.026
Mesolithic S. Europe	1.000		<0.001	0.005	0.445	0.015	0.979	0.005
Neolithic	<0.001	<0.001		0.131	0.041	0.412	<0.001	0.964
Copper Age	0.035	0.005	0.131		1.000	1.000	0.266	1.000
Bronze Age	0.840	0.445	0.041	1.000		1.000	1.000	0.978
Roman	0.079	0.015	0.412	1.000	1.000		0.467	1.000
Medieval	1.000	0.979	<0.001	0.266	1.000	0.467		0.182
Modern	0.026	0.005	0.964	1.000	0.978	1.000	0.182	
				Body mass				
UP S. Europe		1.000	<0.001	<0.001	0.286	<0.001	0.92	0.004
Mesolithic S. Europe	1.000		<0.001	<0.001	0.034	<0.001	0.306	<0.001
Neolithic	<0.001	<0.001		0.065	0.002	1.000	<0.001	0.285
Copper Age	<0.001	<0.001	0.065		0.805	0.848	0.024	1.000
Bronze Age	0.286	0.034	0.002	0.805		0.066	1.000	0.994
Roman	<0.001	<0.001	1.000	0.848	0.066		0.001	0.959
Medieval	0.920	0.306	<0.001	0.024	1.000	0.001		0.345
Modern	0.004	0.000	0.285	1.000	0.994	0.959	0.345	

Table B.2: Results of one-way ANOVAs and Hochberg GT2 post-hoc comparisons for estimated stature (cm) by sex (summarised in Table.5.3).

Time period	UP S. Europe	Mesolithic S. Europe	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Male stature				
UP S. Europe		1.000	<0.001	0.584	1.000	0.070	1.000	0.043
Mesolithic S. Europe	1.000		<0.001	0.471	1.000	0.037	1.000	0.021
Neolithic	<0.001	<0.001		0.092	0.001	0.465	<0.001	0.649
Copper Age	0.584	0.471	0.092		0.992	1.000	0.733	1.000
Bronze Age	1.000	1.000	0.001	0.992		0.502	1.000	0.366
Roman	0.070	0.037	0.465	1.000	0.502		0.083	1.000
Medieval	1.000	1.000	<0.001	0.733	1.000	0.083		0.049
Modern	0.043	0.021	0.649	1.000	0.366	1.000	0.049	
				Female stature				
UP S. Europe		1.000	0.143	0.442	0.784	0.974	0.999	0.099
Mesolithic S. Europe	1.000		0.663	0.942	0.999	1.000	1.000	0.559
Neolithic	0.143	0.663		1.000	1.000	0.920	0.690	1.000
Copper Age	0.442	0.942	1.000		1.000	0.999	0.979	1.000
Bronze Age	0.784	0.999	1.000	1.000		1.000	1.000	0.998
Roman	0.974	1.000	0.920	0.999	1.000		1.000	0.838
Medieval	0.999	1.000	0.690	0.979	1.000	1.000		0.560
Modern	0.099	0.559	1.000	1.000	0.998	0.838	0.560	

Table B.3: Results of one-way ANOVAs and Hochberg GT2 post-hoc comparisons for estimated body mass (Kg) by sex (summarised in Table.5.3).

Time period	UP S. Europe	Mesolithic S. Europe	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Male body mass				
UP S. Europe		1.000	<0.001	0.001	0.879	<0.001	1.000	0.033
Mesolithic S. Europe	1.000		<0.001	0.001	0.861	<0.001	1.000	0.023
Neolithic	<0.001	<0.001		0.967	0.014	1.000	0.000	0.430
Copper Age	0.001	0.001	0.967		0.524	1.000	0.024	1.000
Bronze Age	0.879	0.861	0.014	0.524		0.076	1.000	0.991
Roman	<0.001	<0.001	1.000	1.000	0.076		0.001	0.885
Medieval	1.000	1.000	<0.001	0.024	1.000	0.001		0.343
Modern	0.033	0.023	0.430	1.000	0.991	0.885	0.343	
				Female body mass				
UP S. Europe		1.000	0.053	0.034	0.924	0.044	0.942	0.042
Mesolithic S. Europe	1.000		0.034	0.024	0.663	0.033	0.694	0.027
Neolithic	0.053	0.034		1.000	0.877	1.000	0.822	1.000
Copper Age	0.034	0.024	1.000		0.813	1.000	0.742	1.000
Bronze Age	0.924	0.663	0.877	0.813		0.925	1.000	0.805
Roman	0.044	0.033	1.000	1.000	0.925		0.874	1.000
Medieval	0.942	0.694	0.822	0.742	1.000	0.874		0.739
Modern	0.042	0.027	1.000	1.000	0.805	1.000	0.739	

Table B.4: Results of one-way ANOVA and Games-Howell post-hoc tests exploring spatial trends in body size in the Neolithic and Copper Age (summarised in Table 5.6).

Time period	Neolithic N. Italy	Neolithic S. Italy	Neolithic Sardinia	Copper Age c. Italy	Copper Age Po Valley	Late Neolithic Malta	Copper Age Sardinia	Alpine Beaker
					Stature			
Neolithic N. Italy		0.799	0.993	0.109	0.040	0.014	0.883	0.766
Neolithic S. Italy	0.799		0.999	0.978	0.531	0.572	1.000	0.998
Neolithic Sardinia	0.993	0.999		0.836	0.325	0.343	1.000	0.977
Copper Age c. Italy	0.109	0.978	0.836		0.894	0.939	0.971	1.000
Copper Age Po Valley	0.040	0.531	0.325	0.894		1.000	0.501	0.991
Late Neolithic Malta	0.014	0.572	0.343	0.939	1.000		0.541	0.996
Copper Age Sardinia	0.883	1.000	1.000	0.971	0.501	0.541		0.997
Alpine Beaker	0.766	0.998	0.977	1.000	0.991	0.996	0.997	
					Body mass			
Neolithic N. Italy		1.000	0.999	0.937	0.519	0.320	0.993	0.131
Neolithic S. Italy	1.000		1.000	0.923	0.543	0.440	0.985	0.154
Neolithic Sardinia	0.999	1.000		0.889	0.556	0.521	0.956	0.192
Copper Age c. Italy	0.937	0.923	0.889		0.899	0.820	1.000	0.339
Copper Age Po Valley	0.519	0.543	0.556	0.899		1.000	0.910	0.954
Late Neolithic Malta	0.320	0.440	0.521	0.820	1.000		0.886	0.826
Copper Age Sardinia	0.993	0.985	0.956	1.000	0.910	0.886		0.374
Alpine Beaker	0.131	0.154	0.192	0.339	0.954	0.826	0.374	

APPENDIX C

Table C.1: Summary statistics for mid-distal (35%) I_{max} and I_{min} SMAs of the humerus within the Neolithic and Copper Age samples (left and right combined, pooled sex).

Sample		I_{max}		I_{min}	
	N	Mean	St.d.	Mean	St.d.
Neolithic N. Italy	54	4517.37	1350.89	3709.56	1111.99
Neolithic S. Italy	17	3443.07	972.28	2954.53	906.27
Neolithic Sardinia	17	4027.43	1045.10	3303.92	773.15
Copper Age C. Italy	61	3453.24	1035.98	2882.45	901.12
Copper Age Po Valley	12	2809.36	585.18	2332.10	578.18
Late Neolithic Malta	32	2863.64	769.78	2250.77	650.79
Copper Age Sardinia	24	3725.89	922.07	3088.50	937.39
Alpine Beaker	27	4396.07	1410.42	3509.96	1196.30

Table C.2: Summary statistics for mid-distal (35%) I_x and I_y SMAs of the humerus within the Neolithic and Copper Age samples (left and right combined, pooled sex).

Sample		I_x		I_y	
	N	Mean	St.d.	Mean	St.d.
Neolithic N. Italy	54	4358.77	1336.08	3868.15	1142.23
Neolithic S. Italy	17	3303.77	977.41	3093.82	917.31
Neolithic Sardinia	17	3866.86	1007.16	3464.49	889.18
Copper Age C. Italy	61	3285.61	1032.92	3050.08	929.44
Copper Age Po Valley	12	2682.18	692.37	2459.28	478.31
Late Neolithic Malta	32	2767.70	771.98	2346.70	650.32
Copper Age Sardinia	24	3596.49	907.69	3217.90	975.12
Alpine Beaker	27	3983.09	1296.62	3922.94	1316.80

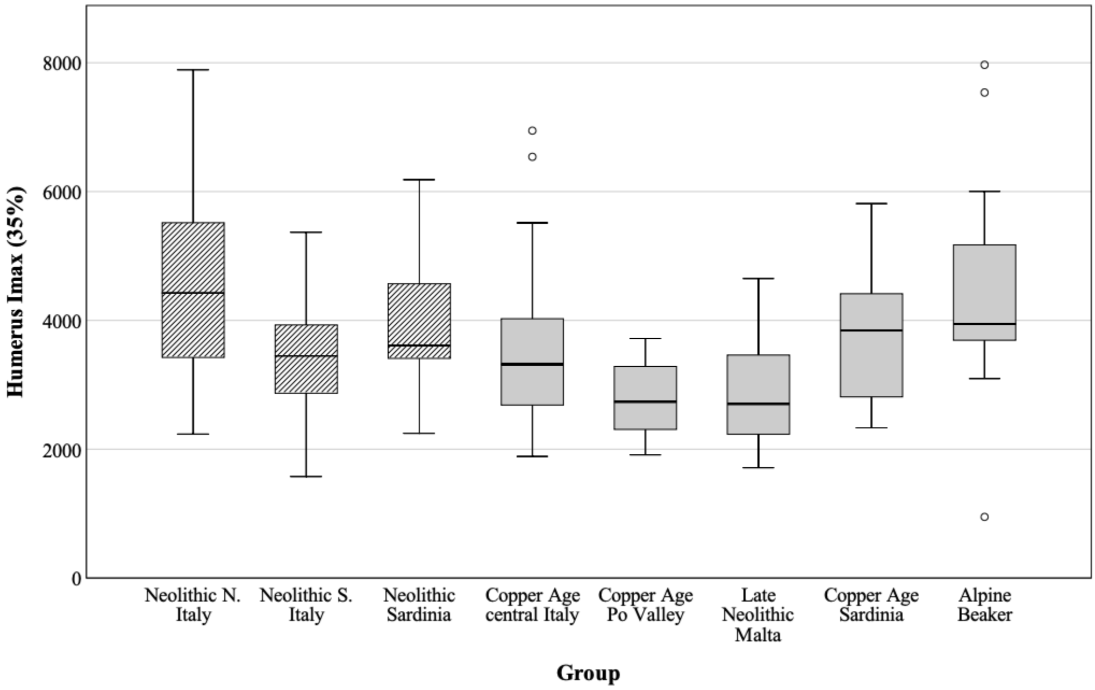

Figure C.1 - Maximum Second Moments of Area (I_{max}) at the mid-distal humerus (35%) within the Neolithic and Copper Age.

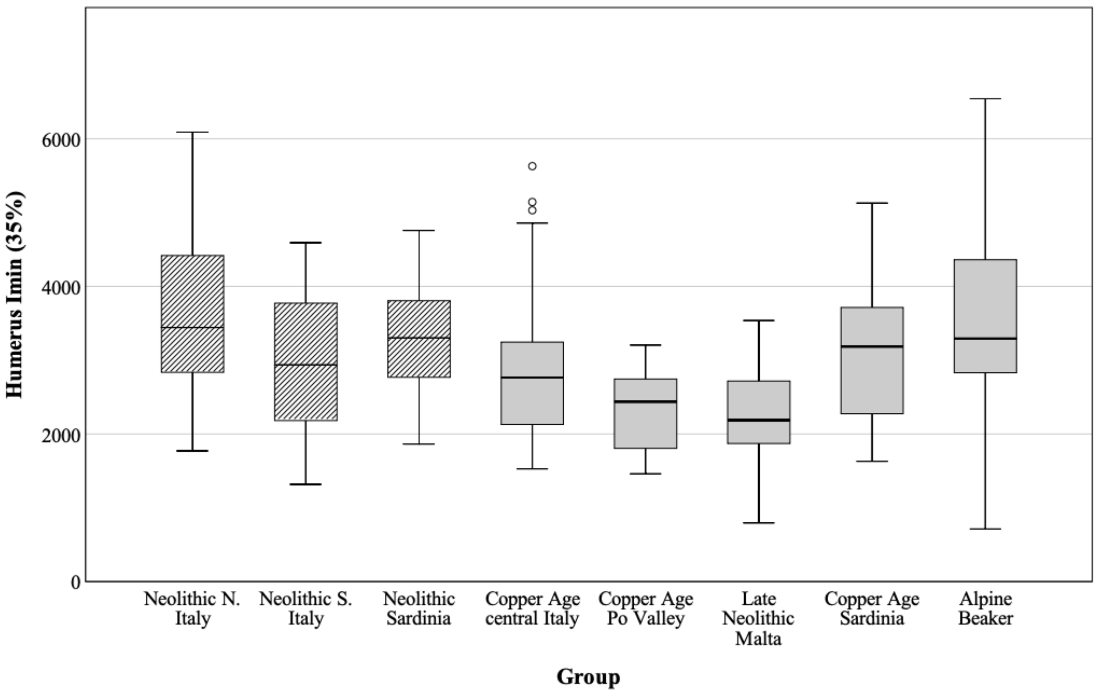

Figure C.2 - Minimum Second Moments of Area (I_{min}) at the mid-distal humerus (35%) within the Neolithic and Copper Age.

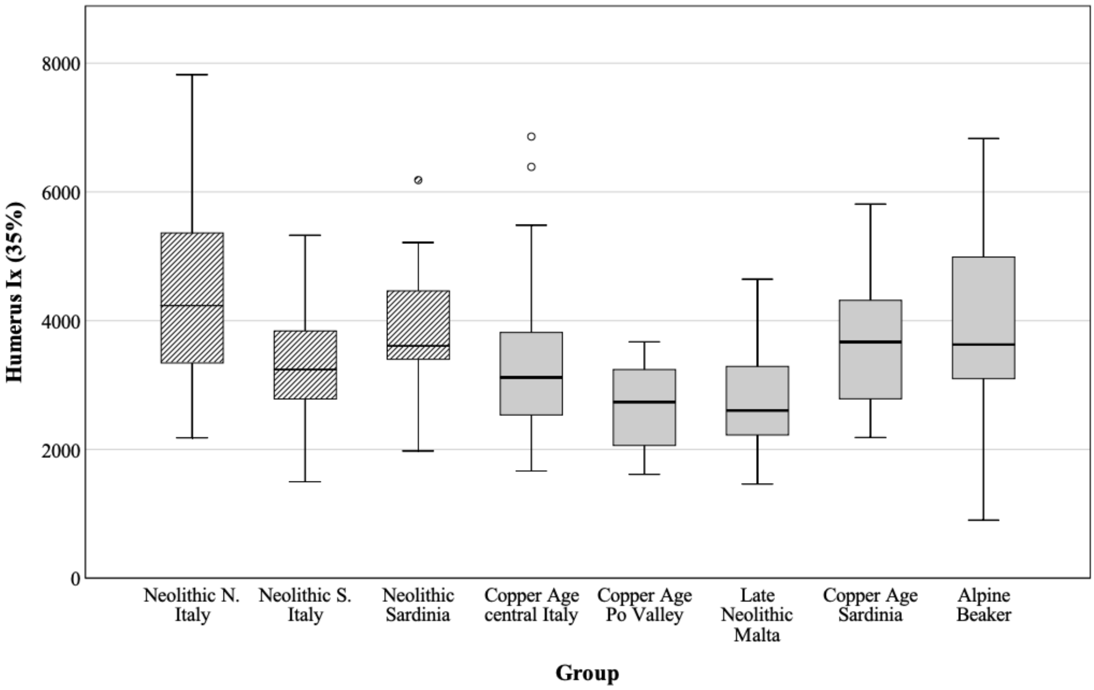

Figure C.3 – Medio-lateral Second Moments of Area (I_x) at the mid-distal humerus (35%) within the Neolithic and Copper Age.

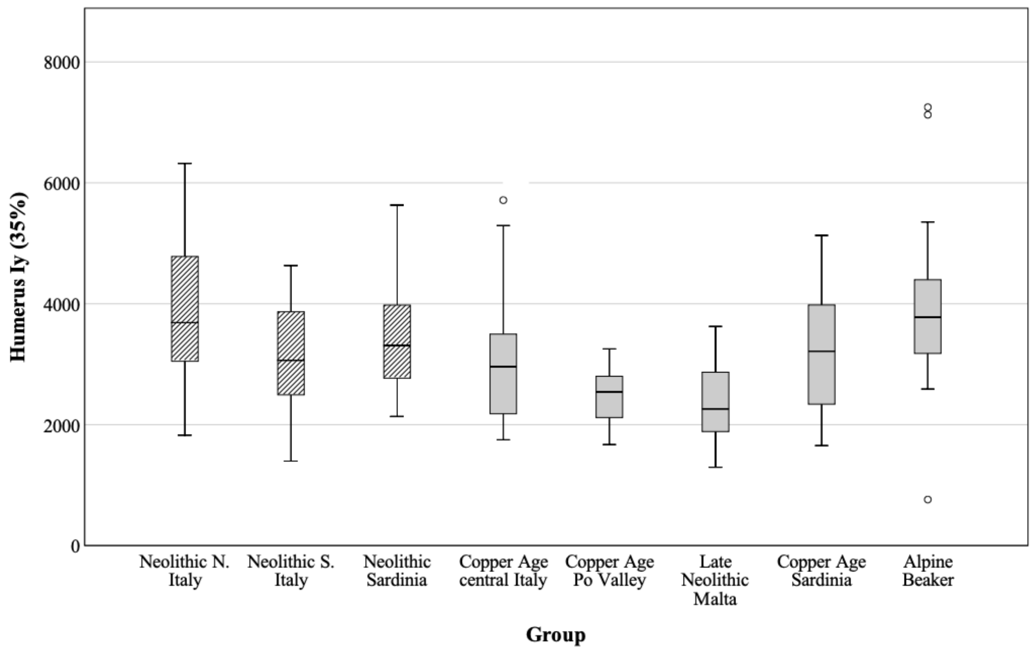

Figure C.4 – Antero-posterior Second Moments of Area (I_y) at the mid-distal humerus (35%) within the Neolithic and Copper Age.

Table C.3: Results Hochberg GT2 post-hoc tests comparing TA at the mid-distal the humerus between time periods (summarised in Table 6.4).

Sample	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				TA (35%)			
Mesolithic		0.005	1.000	0.980	0.999	0.999	1.000
Neolithic	0.005		<0.001	<0.001	0.132	0.132	0.000
Copper Age	1.000	<0.001		0.005	1.000	1.000	1.000
Bronze Age	0.980	<0.001	0.005		0.093	0.093	0.045
Roman	0.999	0.132	1.000	0.093		0.624	1.000
Medieval	1.000	0.000	0.319	0.999	0.624		0.639
Modern	1.000	0.000	1.000	0.045	1.000	1.000	

Table C.4: Results of Hochberg GT2 post-hoc tests comparing mid-distal CSG properties of the humerus between the Neolithic and Copper Age samples (pooled sex) (summarised in Table 6.6).

Sample	Neolithic N. Italy	Neolithic S. Italy	Neolithic Sardinia	Copper Age C. Italy	Copper Age Po Valley	Late Neolithic Malta	Copper Age Sardinia	Alpine Beaker
				TA (35%)				
Neolithic N. Italy		0.049	0.987	<0.001	<0.001	<0.001	0.144	0.999
Neolithic S. Italy	0.049		0.992	1.000	0.886	0.170	1.000	0.789
Neolithic Sardinia	0.987	0.992		0.711	0.071	<0.001	1.000	1.000
Copper Age C. Italy	<0.001	1.000	0.711		0.823	0.021	1.000	0.105
Copper Age Po Valley	<0.001	0.886	0.071	0.823		1.000	0.350	0.009
Late Neolithic Malta	<0.001	0.170	<0.001	0.021	1.000		0.006	0.000
Copper Age Sardinia	0.144	1.000	1.000	1.000	0.350	0.006		0.988
Alpine Beaker	0.999	0.789	1.000	0.105	0.009	<0.001	0.988	
				J (35%)				
Neolithic N. Italy		0.034	0.958	<0.001	<0.001	<0.001	0.121	1.000
Neolithic S. Italy	0.034		0.995	1.000	0.941	0.619	1.000	0.363
Neolithic Sardinia	0.958	0.995		0.87	0.112	0.008	1.000	1.000
Copper Age C. Italy	<0.001	1.000	0.87		0.822	0.151	1.000	0.024
Copper Age Po Valley	<0.001	0.941	0.112	0.822		1.000	0.419	0.003
Late Neolithic Malta	<0.001	0.619	0.008	0.151	1.000		0.054	<0.001
Copper Age Sardinia	0.121	1.000	1.000	1.000	0.419	0.054		0.782
Alpine Beaker	1.000	0.363	1.000	0.024	0.003	<0.001	0.782	
				I_x/I_y (35%)				
Neolithic N. Italy		0.997	1.000	0.982	1	0.944	1.000	0.108
Neolithic S. Italy	0.997		1.000	1.000	1.000	0.358	0.984	1.000
Neolithic Sardinia	1.000	1.000		1.000	1.000	0.997	1.000	0.609
Copper Age C. Italy	0.982	1.000	1.000		1.000	0.092	0.961	0.896
Copper Age Po Valley	1.000	1.000	1.000	1.000		0.680	0.999	1.000
Late Neolithic Malta	0.944	0.358	0.997	0.092	0.680		1.000	0.002
Copper Age Sardinia	1.000	0.984	1.000	0.961	0.999	1.000		0.137
Alpine Beaker	0.108	1.000	0.609	0.896	1.000	0.002	0.137	

Table C.5: Post-hoc Kruskal-Wallis tests comparing %DA in MXL and I_x/I_y in the humerus (35%) among males by time period (summarised in Table 6.9). Post-hoc comparisons were only performed in cases where the Kruskal-Wallis test identified significant differences.

Sample	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				[a] %DA in MXL			
Mesolithic		1.000	1.000	0.135	0.014	0.119	1.000
Neolithic	1.000		1.000	0.316	0.037	0.318	1.000
Copper Age	1.000	1.000		0.236	0.028	0.240	1.000
Bronze Age	0.135	0.316	0.236		1.000	1.000	1.000
Roman	0.014	0.037	0.028	1.000		1.000	0.094
Medieval	0.119	0.318	0.240	1.000	1.000		0.916
Modern	1.000	1.000	1.000	1.000	0.094	0.916	
				%DA in I_x/I_y			
Mesolithic		1.000	1.000	0.102	1.000	0.019	0.357
Neolithic	1.000		1.000	0.988	1.000	0.151	1.000
Copper Age	1.000	1.000		0.770	1.000	0.009	0.438
Bronze Age	0.102	0.988	0.770		1.000	1.000	1.000
Roman	1.000	1.000	1.000	1.000		1.000	1.000
Medieval	0.019	0.151	0.009	1.000	1.000		1.000
Modern	0.357	1.000	0.438	1.000	1.000	1.000	

Table C.6: Results of ANOVA and Hochberg GT2[a]/Games-Howell[b] post-hoc tests exploring temporal differences in %AA in the humerus (35%) among males.

Sample	Mesolithic S. Europe	Neolithic Italy	Copper Age Italy	Bronze Age Italy	Roman Italy	Medieval Italy	Modern Italy
				%AA in MXL [a]			
Mesolithic S. Europe		1.000	1.000	0.999	0.238	0.990	1.000
Neolithic Italy	1.000		1.000	1.000	0.208	0.999	1.000
Copper Age Italy	1.000	1.000		0.891	0.045	0.745	1.000
Bronze Age Italy	0.999	1.000	0.891		0.495	1.000	0.992
Roman Italy	0.238	0.208	0.045	0.495		0.780	0.086
Medieval Italy	0.990	0.999	0.745	1.000	0.780		0.943
Modern Italy	1.000	1.000	1.000	0.992	0.086	0.943	
				%A in TA [b]			
Mesolithic S. Europe		0.008	0.014	0.527	0.824	0.006	0.138
Neolithic Italy	0.008		0.715	0.192	1.000	0.988	0.999
Copper Age Italy	0.014	0.715		0.061	0.983	0.954	0.580
Bronze Age Italy	0.527	0.192	0.061		0.957	0.062	0.701
Roman Italy	0.824	1.000	0.983	0.957		1.000	1.000
Medieval Italy	0.006	0.988	0.954	0.062	1.000		0.926
Modern Italy	0.138	0.999	0.580	0.701	1.000	0.926	
				%AA in J [a]			
Mesolithic S. Europe		0.990	0.316	1.000	1.000	0.565	0.996
Neolithic Italy	0.990		0.877	0.968	1.000	0.994	1.000
Copper Age Italy	0.316	0.877		0.076	0.970	1.000	0.754
Bronze Age Italy	1.000	0.968	0.076		1.000	0.270	0.991
Roman Italy	1.000	1.000	0.970	1.000		0.998	1.000
Medieval Italy	0.565	0.994	1.000	0.270	0.998		0.974
Modern Italy	0.996	1.000	0.754	0.991	1.000	0.974	
				%AA in I_x/I_y [b]			
Mesolithic S. Europe		0.050	0.085	0.064	0.049	0.211	0.170
Neolithic Italy	0.050		0.667	0.881	1.000	0.106	0.133
Copper Age Italy	0.085	0.667		0.970	0.644	0.862	0.950
Bronze Age Italy	0.064	0.881	0.970		0.854	0.297	0.413
Roman Italy	0.049	1.000	0.644	0.854		0.102	0.128
Medieval Italy	0.211	0.106	0.862	0.297	0.102		1.000
Modern Italy	0.170	0.133	0.950	0.413	0.128	1.000	

Table C.7: Results of ANOVA and Hochberg GT2[a]/Games-Howell[b] post-hoc tests exploring temporal differences in %AA in the humerus (35%) among females.

Sample	Mesolithic S. Europe	Neolithic Italy	Copper Age Italy	Bronze Age Italy	Roman Italy	Medieval Italy	Modern Italy
			%AA in MXL [a]				
Mesolithic S. Europe		0.773	0.977	0.981	0.711	0.999	1.000
Neolithic Italy	0.773		1.000	0.999	1.000	0.961	0.376
Copper Age Italy	0.977	1.000		1.000	0.997	1.000	0.811
Bronze Age Italy	0.981	0.999	1.000		0.994	1.000	0.809
Roman Italy	0.711	1.000	0.997	0.994		0.947	0.548
Medieval Italy	0.999	0.961	1.000	1.000	0.947		0.993
Modern Italy	1.000	0.376	0.811	0.809	0.548	0.993	
			%A in TA [b]				
Mesolithic S. Europe		0.058	1.000	0.002	0.989	1.000	1.000
Neolithic Italy	0.058		0.495	0.998	0.809	0.213	0.663
Copper Age Italy	1.000	0.495		0.601	0.998	1.000	1.000
Bronze Age Italy	0.002	0.998	0.601		0.847	0.255	0.751
Roman Italy	0.989	0.809	0.998	0.847		0.986	0.999
Medieval Italy	1.000	0.213	1.000	0.255	0.986		1.000
Modern Italy	1.000	0.663	1.000	0.751	0.999	1.000	
			%AA in J [b]				
Mesolithic S. Europe		0.044	1.000	0.012	1.000	1.000	1.000
Neolithic Italy	0.044		0.519	0.986	0.852	0.278	0.580
Copper Age Italy	1.000	0.519		0.711	1.000	1.000	1.000
Bronze Age Italy	0.012	0.986	0.711		0.920	0.480	0.769
Roman Italy	1.000	0.852	1.000	0.920		1.000	1.000
Medieval Italy	1.000	0.278	1.000	0.480	1.000		1.000
Modern Italy	1.000	0.580	1.000	0.769	1.000	1.000	
			%AA in I_x/I_y [a]				
Mesolithic S. Europe		1.000	1.000	1.000	0.990	1.000	1.000
Neolithic Italy	1.000		0.998	1.000	0.200	0.502	0.953
Copper Age Italy	1.000	0.998		1.000	0.630	0.985	1.000
Bronze Age Italy	1.000	1.000	1.000		0.311	0.679	0.999
Roman Italy	0.990	0.200	0.630	0.311		0.997	0.925
Medieval Italy	1.000	0.502	0.985	0.679	0.997		1.000
Modern Italy	1.000	0.953	1.000	0.999	0.925	1.000	

APPENDIX D

Table D.1: Summary statistics for mid-shaft (50%) I_{max} and I_{min} SMAs of the femur within the Neolithic and Copper Age samples.

Sample	***N***	I_{max}		I_{min}	
		Mean	St.d.	Mean	St.d.
Neolithic N. Italy	24	2520.25	731.72	1906.09	431.88
Neolithic Sardinia	15	2223.03	314.74	1763.35	306.19
Copper Age c. Italy	32	2237.04	504.30	1710.50	355.88
Copper Age Po Valley	8	2205.91	480.02	1616.81	214.74
Late Neolithic Malta	31	2299.33	509.19	1798.38	481.66
Copper Age Sardinia	30	2142.82	578.62	1675.25	405.19
Alpine Beaker	13	2068.93	378.93	1647.52	353.57

Table D.2: Summary statistics for mid-shaft (50%) I_x and I_y SMAs of the femur within the Neolithic and Copper Age samples.

Sample	***N***	I_x		I_y	
		Mean	St.d.	Mean	St.d.
Neolithic N. Italy	24	2440.16	717.57	1986.17	448.91
Neolithic Sardinia	15	2162.30	325.47	1824.08	315.67
Copper Age c. Italy	32	2087.44	478.09	1860.10	443.93
Copper Age Po Valley	8	2145.59	499.15	1677.13	229.94
Late Neolithic Malta	31	2240.66	504.54	1857.05	504.68
Copper Age Sardinia	30	2057.77	571.83	1760.30	429.32
Alpine Beaker	13	2025.56	377.83	1690.89	368.80

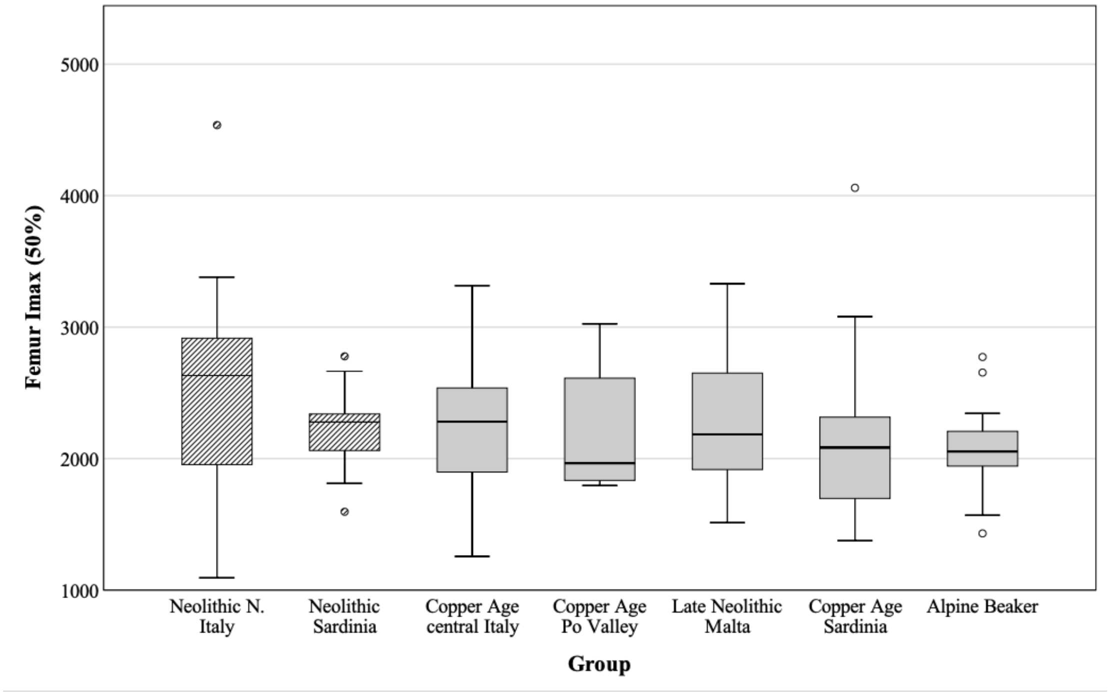

Figure D.1 - Maximum Second Moments of Area (I_{max}) at the mid-shaft femur (50%) within the Neolithic and Copper Age.

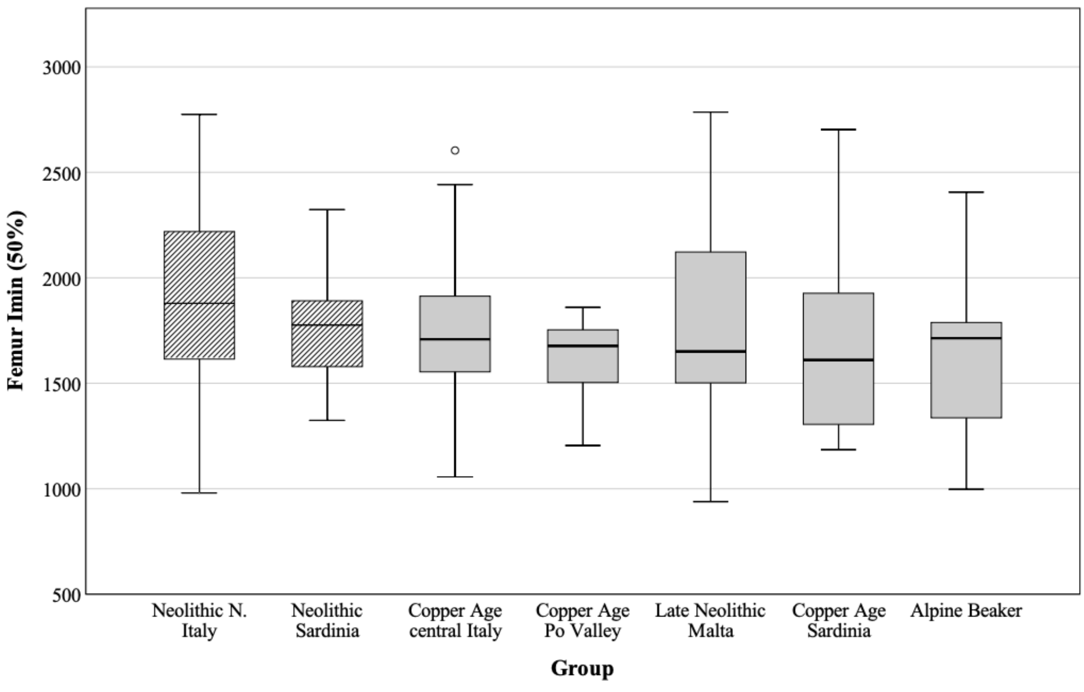

Figure D.2 - Minimum Second Moments of Area (I_{min}) at the mid-shaft femur (50%) within the Neolithic and Copper Age.

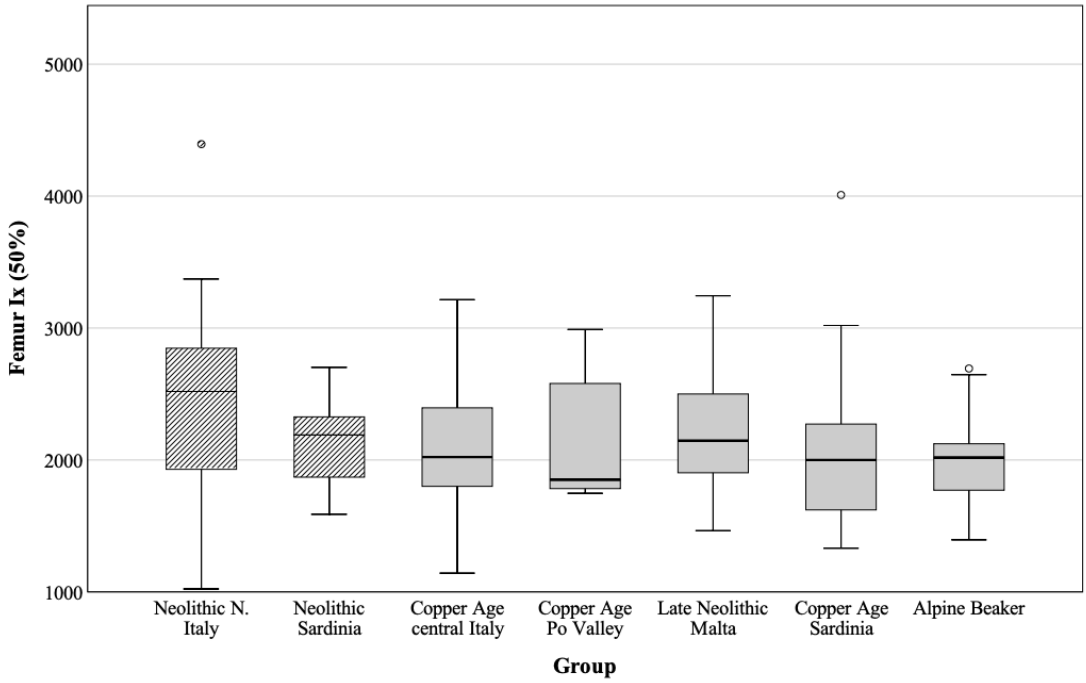

Figure D.3 - Medio-lateral Second Moments of Area (I_x) at the mid-shaft femur (50%) within the Neolithic and Copper Age.

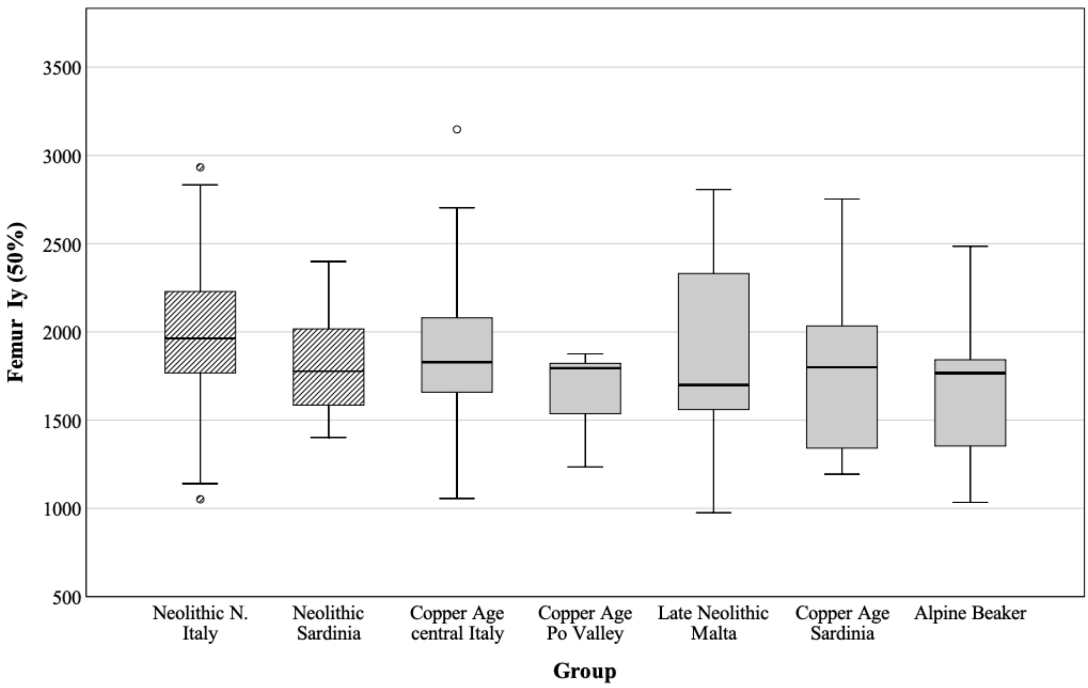

Figure D.4 – Antero-posterior Second Moments of Area (I_y) at the mid-shaft femur (50%) within the Neolithic and Copper Age.

Table D.3: Summary statistics for mid-shaft (50%) I_{max} and I_{min} SMAs of the tibia within the Neolithic and Copper Age samples.

Sample	***N***	***I_{max}***		***I_{min}***	
		Mean	St.d.	Mean	St.d.
Neolithic N. Italy	27	3589.26	935.49	1483.76	357.23
Neolithic S. Italy	9	3732.83	1145.72	1518.83	508.21
Neolithic Sardinia	15	3099.06	791.50	1532.01	391.37
Copper Age C. Italy	32	2995.78	733.57	1268.37	358.30
Copper Age Po Valley	5	2860.21	631.33	1104.37	159.85
Late Neolithic Malta	27	3045.84	691.05	1373.95	344.73
Copper Age Sardinia	27	3533.26	939.21	1446.47	319.58
Alpine Beaker	13	3183.08	753.10	1591.72	405.12

Table D.4: Summary statistics for mid-shaft (50%) I_x and I_y SMAs of the tibia within the Neolithic and Copper Age samples.

Sample	***N***	***I_x***		***I_y***	
		Mean	St.d.	Mean	St.d.
Neolithic N. Italy	27	3089.45	750.54	1983.57	544.12
Neolithic S. Italy	9	3349.54	1017.89	1902.12	667.65
Neolithic Sardinia	15	2787.40	774.87	1843.67	432.15
Copper Age C. Italy	32	2618.66	595.39	1645.49	498.07
Copper Age Po Valley	5	2673.01	574.64	1291.56	441.13
Late Neolithic Malta	27	2603.73	577.55	1816.07	392.74
Copper Age Sardinia	27	3182.53	837.68	1797.20	409.13
Alpine Beaker	13	2957.75	665.56	1817.06	483.76

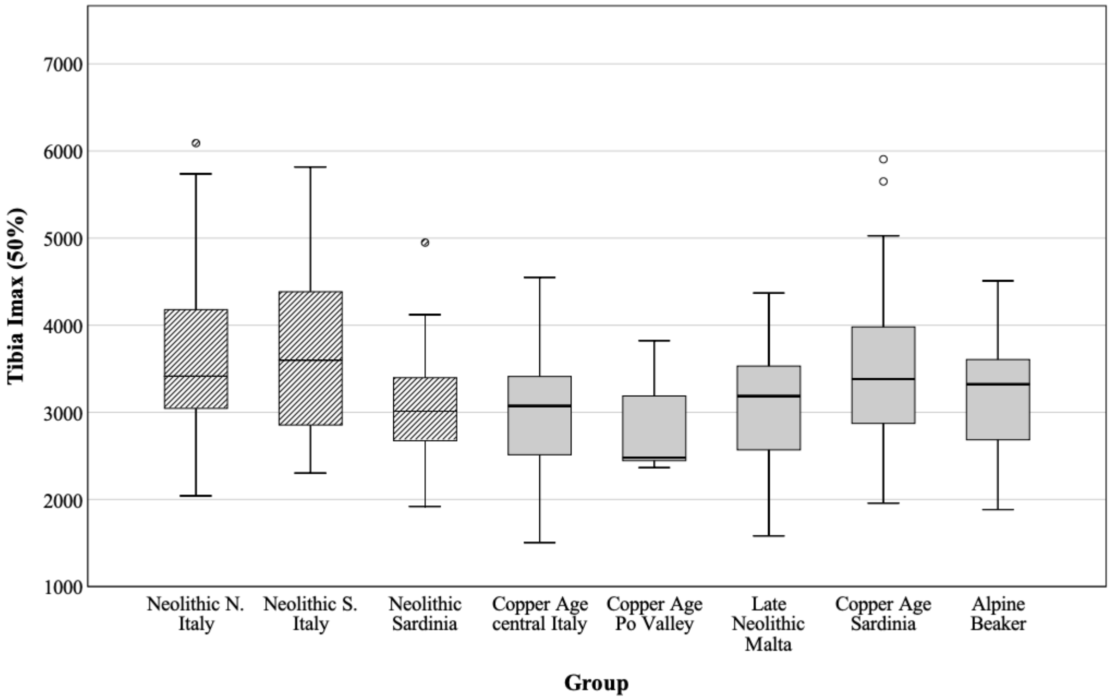

Figure D.5 - Maximum Second Moments of Area (I_{max}) at the mid-shaft tibia (50%) within the Neolithic and Copper Age.

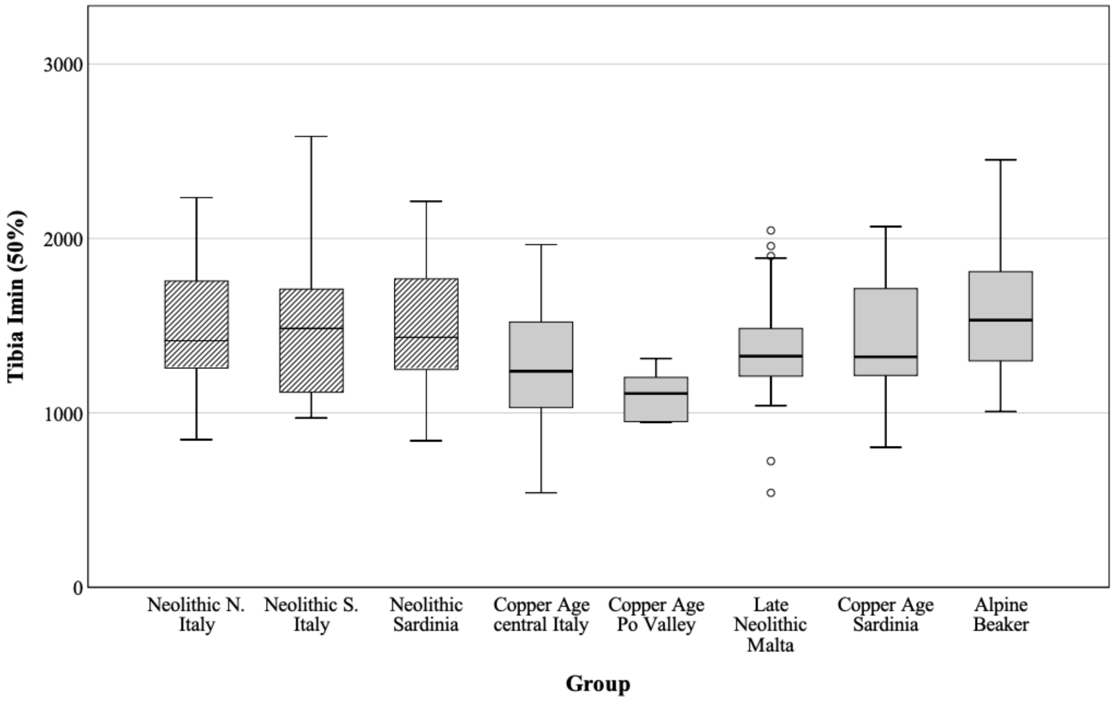

Figure D.6 - Minimum Second Moments of Area (I_{min}) at the mid-shaft femur (50%) within the Neolithic and Copper Age.

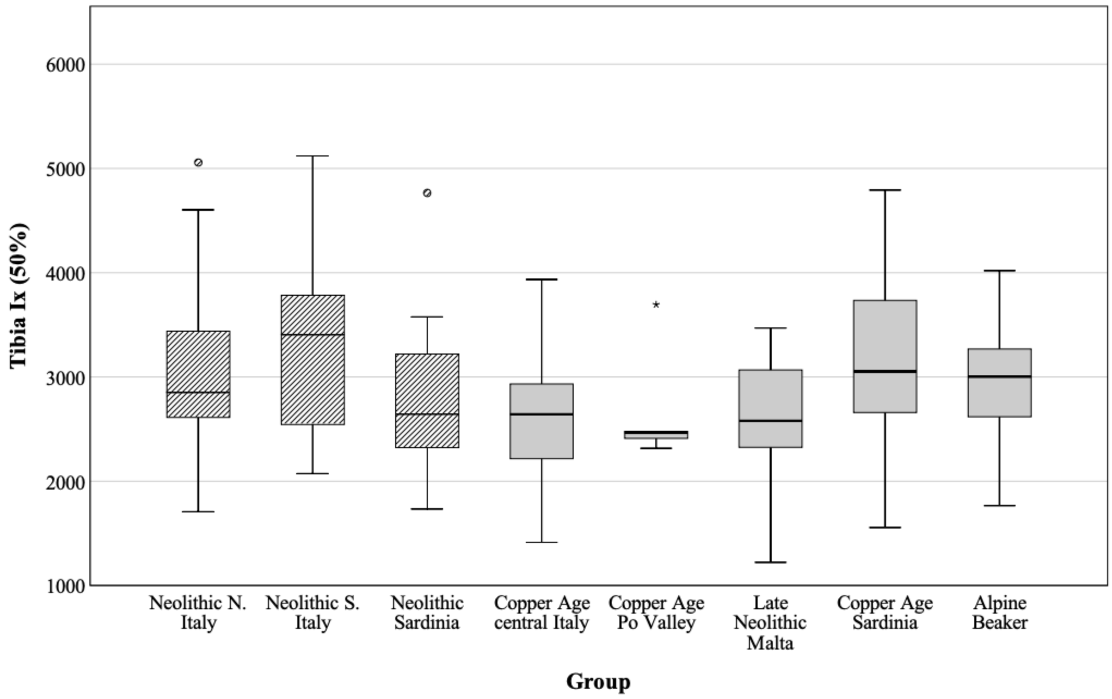

Figure D.7 - Medio-lateral Second Moments of Area (I_x) at the mid-shaft tibia (50%) within the Neolithic and Copper Age.

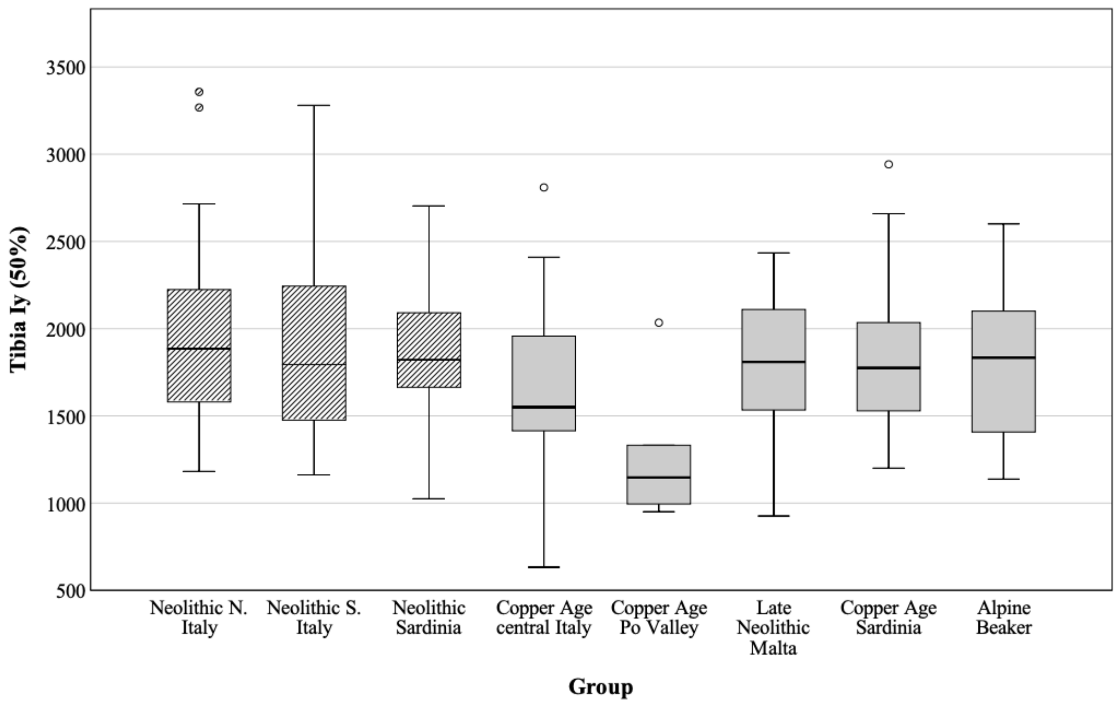

Figure D.8 - Antero-posterior Second Moments of Area (I_y) at the mid-shaft tibia (50%) within the Neolithic and Copper Age.

Table D.5: Hochberg GT2[a] and Games-Howell[b] post-hoc tests comparing TA and I_{max}/I_{min} at the mid-shaft of the femur between time periods (summarised in Table 7.4).

Time period	Upper Pal.	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Femur TA (50%) [a]				
Upper Pal.		1.000	0.924	0.311	<0.001	1.000	0.889	0.629
Mesolithic	1.000		0.692	0.110	<0.001	1.000	0.622	0.344
Neolithic	0.924	0.692		1.000	<0.001	0.977	1.000	1.000
Copper Age	0.311	0.110	1.000		<0.001	0.401	1.000	1.000
Bronze Age	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	0.016
Roman	1.000	1.000	0.977	0.401	<0.001		0.959	0.759
Medieval	0.889	0.622	1.000	1.000	<0.001	0.959		1.000
Modern	0.629	0.344	1.000	1.000	0.016	0.759	1.000	
				Femur I_{max}/I_{min} (50%) [b]				
Upper Pal.		0.493	0.005	<0.001	0.032	0.002	0.013	0.315
Mesolithic	0.493		0.943	0.881	0.995	0.902	0.994	1.000
Neolithic	0.005	0.943		1.000	1.000	1.000	0.999	0.925
Copper Age	<0.001	0.881	1.000		0.998	1.000	0.993	0.818
Bronze Age	0.032	0.995	1.000	0.998		0.999	1.000	0.995
Roman	0.002	0.902	1.000	1.000	0.999		0.996	0.861
Medieval	0.013	0.994	0.999	0.993	1.000	0.996		0.992
Modern	0.315	1.000	0.925	0.818	0.995	0.861	0.9920	

Table D.6: Hochberg GT2[a] post-hoc tests comparing TA and I_{max}/I_{min} at the mid-shaft of the tibia between time periods (summarised in Table 7.4).

Time period	Upper Pal.	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Tibia TA (50%) [a]				
Upper Pal.		1.000	1.000	0.207	<0.001	0.724	0.003	0.002
Mesolithic	1.000		0.999	0.055	<0.001	0.378	<0.001	<0.001
Neolithic	1.000	0.999		0.154	<0.001	0.929	<0.001	<0.001
Copper Age	0.207	0.055	0.154		0.010	1.000	0.425	0.303
Bronze Age	<0.001	<0.001	<0.001	0.010		0.038	0.999	1.000
Roman	0.724	0.378	0.929	1.000	0.038		0.575	0.424
Medieval	0.003	<0.001	<0.001	0.425	0.999	0.575		1.000
Modern	0.002	<0.001	<0.001	0.303	1.000	0.424	1.0000	
				Tibia I_{max}/I_{min} (50%) [a]				
Upper Pal.		1.000	0.996	0.993	1.000	0.344	0.014	0.113
Mesolithic	1.000		1.000	1.000	1.000	0.980	0.291	0.785
Neolithic	0.996	1.000		1.000	1.000	0.960	0.069	0.578
Copper Age	0.993	1.000	1.000		1.000	0.856	0.015	0.329
Bronze Age	1.000	1.000	1.000	1.000		0.585	0.018	0.199
Roman	0.344	0.980	0.960	0.856	0.585		1.000	1.000
Medieval	0.014	0.291	0.069	0.015	0.018	1.000		1.000
Modern	0.113	0.785	0.578	0.329	0.199	1.000	1.000	

Table D.7: Hochberg GT2[a] and Games-Howell[b] post-hoc comparisons for temporal trends in mid-shaft CSG properties of the femur in males by time period (summarised in Table 7.5).

Time period	Upper Pal.	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Femur TA (50%) [a]				
Upper Pal.		1.000	1.000	0.999	<0.001	1.000	1.000	0.844
Mesolithic	1.000		0.995	0.683	<0.001	1.000	0.711	0.181
Neolithic	1.000	0.995		1.000	0.025	1.000	1.000	1.000
Copper Age	0.999	0.683	1.000		0.031	0.996	1.000	1.000
Bronze Age	<0.001	<0.001	0.025	0.031		<0.001	0.020	0.234
Roman	1.000	1.000	1.000	0.996	<0.001		0.998	0.761
Medieval	1.000	0.711	1.000	1.000	0.020	0.998		1.000
Modern	0.844	0.181	1.000	1.000	0.234	0.761	1.000	
				Femur I_{max}/I_{min} (50%) [b]				
Upper Pal.		0.852	0.669	0.033	0.010	0.031	0.152	0.011
Mesolithic	0.852		1.000	0.811	0.591	0.774	0.988	0.648
Neolithic	0.669	1.000		0.966	0.862	0.951	1.000	0.902
Copper Age	0.033	0.811	0.966		1.000	1.000	0.989	1.000
Bronze Age	0.010	0.591	0.862	1.000		1.000	0.874	1.000
Roman	0.031	0.774	0.951	1.000	1.000		0.979	1.000
Medieval	0.152	0.988	1.000	0.989	0.874	0.979		0.921
Modern	0.011	0.648	0.902	1.000	1.000	1.000	0.921	

Table D.8: Hochberg GT2 post-hoc comparisons for temporal trends in mid-shaft CSG properties of the tibia in males by time period (summarised in Table 7.5).

Time period	Upper Pal.	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Tibia TA (50%) [a]				
Upper Pal.		1.000	1.000	0.995	0.293	0.999	0.059	0.010
Mesolithic	1.000		1.000	0.474	0.018	0.664	<0.001	<0.001
Neolithic	1.000	1.000		0.918	0.068	0.982	0.004	<0.001
Copper Age	0.995	0.474	0.918		0.979	1.000	0.597	0.140
Bronze Age	0.293	0.018	0.068	0.979		0.970	1.000	1.000
Roman	0.999	0.664	0.982	1.000	0.970		0.588	0.149
Medieval	0.059	<0.001	0.004	0.597	1.000	0.588		1.000
Modern	0.010	<0.001	<0.001	0.140	1.000	0.149	1.0000	
				Tibia I_{max}/I_{min} (50%) [a]				
Upper Pal.		0.917	0.949	0.216	0.965	0.196	<0.001	0.006
Mesolithic	0.917		1.000	1.000	1.000	1.000	0.281	0.703
Neolithic	0.949	1.000		0.997	1.000	0.991	0.030	0.191
Copper Age	0.216	1.000	0.997		1.000	1.000	0.749	0.992
Bronze Age	0.965	1.000	1.000	1.000		0.999	0.116	0.430
Roman	0.196	1.000	0.991	1.000	0.999		0.923	1.000
Medieval	<0.001	0.281	0.030	0.749	0.116	0.923		1.000
Modern	0.006	0.703	0.191	0.992	0.43	1.000	1.000	

Table D.9: Hochberg GT2[a] and Games-Howell[b] post-hoc comparisons for temporal trends in mid-shaft CSG properties of the tibia in females by time period (summarised in Table 7.5).

Time period	Upper Pal.	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Femur TA (50%) [a]				
Upper Pal.		1.000	1.000	0.999	0.014	1.000	0.977	0.991
Mesolithic	1.000		1.000	1.000	0.765	1.000	1.000	1.000
Neolithic	1.000	1.000		1.000	0.552	1.000	1.000	1.000
Copper Age	0.999	1.000	1.000		0.193	1.000	1.000	1.000
Bronze Age	0.014	0.765	0.552	0.193		0.006	0.307	0.561
Roman	1.000	1.000	1.000	1.000	0.006		0.982	0.995
Medieval	0.977	1.000	1.000	1.000	0.307	0.982		1.000
Modern	0.991	1.000	1.000	1.000	0.561	0.995	1.000	
				Femur I_{max}/I_{min} (50%) [b]				
Upper Pal.		0.032	0.112	0.395	0.984	0.251	0.232	0.999
Mesolithic	0.032		1.000	0.541	0.438	0.583	0.879	0.285
Neolithic	0.112	1.000		0.870	0.668	0.912	0.985	0.372
Copper Age	0.395	0.541	0.870		0.990	1.000	0.999	0.701
Bronze Age	0.984	0.438	0.668	0.990		0.967	0.937	0.960
Roman	0.251	0.583	0.912	1.000	0.967		1.000	0.631
Medieval	0.232	0.879	0.985	0.999	0.937	1.000		0.58
Modern	0.999	0.285	0.372	0.701	0.960	0.631	0.5800	

Table D.10: Hochberg GT2 post-hoc comparisons for temporal trends in mid-shaft CSG properties of the tibia in females by time period (summarised in Table 7.5).

Time period	Upper Pal.	Mesolithic	Neolithic	Copper Age	Bronze Age	Roman	Medieval	Modern
				Tibia TA (50%) [a]				
Upper Pal.		0.747	0.989	0.170	<0.001	0.631	0.046	0.158
Mesolithic	0.747		1.000	1.000	0.912	1.000	1.000	1.000
Neolithic	0.989	1.000		0.968	<0.001	1.000	0.668	0.946
Copper Age	0.170	1.000	0.968		0.120	1.000	1.000	1.000
Bronze Age	<0.001	0.912	<0.001	0.120		0.009	0.289	0.313
Roman	0.631	1.000	1.000	1.000	0.009		0.991	1.000
Medieval	0.046	1.000	0.668	1.000	0.289	0.991		1.000
Modern	0.158	1.000	0.946	1.000	0.313	1.000	1.0000	
				Tibia I_{max}/I_{min} (50%) [a]				
Upper Pal.		1.000	0.924	0.214	0.938	1.000	1.000	1.000
Mesolithic	1.000		0.995	0.671	0.998	1.000	1.000	1.000
Neolithic	0.924	0.995		1.000	1.000	0.623	0.661	0.926
Copper Age	0.214	0.671	1.000		0.989	0.026	0.024	0.135
Bronze Age	0.938	0.998	1.000	0.989		0.592	0.623	0.935
Roman	1.000	1.000	0.623	0.026	0.592		1.000	1.000
Medieval	1.000	1.000	0.661	0.024	0.623	1.000		1.000
Modern	1.000	1.000	0.926	0.135	0.935	1.000	1.000	

Table D.11: Results of Games-Howell post-hoc comparisons of mid-shaft (50%) CSG properties of the femur between the individual Neolithic and Copper Age samples (summarised in Table 7.8).

Sample	Neolithic N. Italy	Neolithic Sardinia	Copper Age c. Italy	Copper Age Po Valley	Late Neolithic Malta	Copper Age Sardinia	Alpine Beaker
				TA			
Neolithic N. Italy		0.972	1.000	1.000	1.000	0.851	0.506
Neolithic Sardinia	0.972		0.982	1.000	0.919	0.999	0.835
Copper Age c. Italy	1.000	0.982		1.000	0.999	0.830	0.503
Copper Age Po Valley	1.000	1.000	1.000		0.999	0.994	0.824
Late Neolithic Malta	1.000	0.919	0.999	0.999		0.680	0.398
Copper Age Sardinia	0.851	0.999	0.830	0.994	0.680		0.935
Alpine Beaker	0.506	0.835	0.503	0.824	0.398	0.935	
				J			
Neolithic N. Italy		0.656	0.559	0.510	0.903	0.342	0.236
Neolithic Sardinia	0.656		1.000	0.996	0.999	0.989	0.923
Copper Age c. Italy	0.559	1.000		0.999	0.994	0.997	0.962
Copper Age Po Valley	0.510	0.996	0.999		0.956	1.000	1.000
Late Neolithic Malta	0.903	0.999	0.994	0.956		0.912	0.766
Copper Age Sardinia	0.342	0.989	0.997	1.000	0.912		1.000
Alpine Beaker	0.236	0.923	0.962	1.000	0.766	1.000	
				I_x/I_y			
Neolithic N. Italy		0.993	1.000	0.999	1.000	0.996	0.983
Neolithic Sardinia	0.993		0.992	0.936	0.998	1.000	1.000
Copper Age c. Italy	1.000	0.992		0.993	1.000	0.995	0.974
Copper Age Po Valley	0.999	0.936	0.993		0.989	0.941	0.903
Late Neolithic Malta	1.000	0.998	1.000	0.989		0.999	0.990
Copper Age Sardinia	0.996	1.000	0.995	0.941	0.999		1.000
Alpine Beaker	0.983	1.000	0.974	0.903	0.990	1.000	

Table D.12: Results of Hochberg GT2 post-hoc comparisons of mid-shaft (50%) CSG properties of the tibia between the individual Neolithic and Copper Age samples (summarised in Table 7.10).

Sample	Neolithic N. Italy	Neolithic S. Italy	Neolithic Sardinia	Copper Age C. Italy	Copper Age Po Valley	Late Neolithic Malta	Copper Age Sardinia	Alpine Beaker
				TA (50%) [b]				
Neolithic N. Italy		0.999	1.000	0.742	0.632	0.750	0.973	0.986
Neolithic S. Italy	0.999		1.000	0.705	0.552	0.692	0.896	0.927
Neolithic Sardinia	1.000	1.000		0.852	0.669	0.836	0.965	0.975
Copper Age C. Italy	0.742	0.705	0.852		0.979	1.000	1.000	1.000
Copper Age Po Valley	0.632	0.552	0.669	0.979		0.993	0.928	0.962
Late Neolithic Malta	0.750	0.692	0.836	1.000	0.993		0.999	1.000
Copper Age Sardinia	0.973	0.896	0.965	1.000	0.928	0.999		1.000
Alpine Beaker	0.986	0.927	0.975	1.000	0.962	1.000	1.000	
				J (50%) [b]				
Neolithic N. Italy		1.000	0.935	0.150	0.246	0.379	1.000	0.994
Neolithic S. Italy	1.000		0.964	0.670	0.507	0.810	1.000	0.992
Neolithic Sardinia	0.935	0.964		0.959	0.799	0.998	0.979	1.000
Copper Age C. Italy	0.150	0.670	0.959		0.989	0.999	0.238	0.837
Copper Age Po Valley	0.246	0.507	0.799	0.989		0.912	0.313	0.650
Late Neolithic Malta	0.379	0.810	0.998	0.999	0.912		0.536	0.970
Copper Age Sardinia	1.000	1.000	0.979	0.238	0.313	0.536		0.999
Alpine Beaker	0.994	0.992	1.000	0.837	0.650	0.970	0.999	
				Imax/Imin (50%) [a]				
Neolithic N. Italy		1.000	0.072	1.000	1	0.988	1.000	0.070
Neolithic S. Italy	1.000		0.237	1.000	1.000	0.996	1.000	0.212
Neolithic Sardinia	0.072	0.237		0.090	0.275	0.842	0.162	1.000
Copper Age C. Italy	1.000	1.000	0.090		1.000	0.997	1.000	0.088
Copper Age Po Valley	1.000	1.000	0.275	1.000		0.981	1.000	0.245
Late Neolithic Malta	0.988	0.996	0.842	0.997	0.981		1.000	0.796
Copper Age Sardinia	1.000	1.000	0.162	1.000	1.000	1.000		0.152
Alpine Beaker	0.070	0.212	1.000	0.088	0.245	0.796	0.152	